The City of Tyre, Lebanon and Its Semi-Artificial Tombolo

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The sedimentological history of the peninsular city of Tyre, located on the southern coast of Lebanon, reflects the political events surrounding Alexander the Great's conquest of the East (332 B.C.E.). Like many other Phoenician settlements, the city was originally situated on a small, relict rocky islet, but was later connected to the mainland by an artificial causeway constructed by Alexander's troops. As a result of the causeway construction, a gigantic tombolo formed, composed of at least 10 million m^3 of sediment, mostly sand. Calculations based on the present size of the land tombolo of Tyre show that the average regional yearly volume of sand drift from the south and the north for the past 2300 years was approximately 4000 m^3. If the present composition of high carbonate tombolo sands is representative of the entire sand body of the tombolo, about two thirds of the mass originates from nearby beaches which formed as a result of the erosion of the Pleistocene carbonate sandstone known as "Hajar Ramli."

INTRODUCTION

The peninsula of Tyre has been known to be an exceptional morphological feature that has resulted from human intervention in coastal processes through blocking the regional longshore currents regime. This article analyzes this developed geological feature and its historical influence on the entire southern Lebanon coasts, illustrating how long-term changes in the coastline were initiated through the construction of the causeway of Tyre.

The Lebanese coastal belt and inner continental shelf sediments were studied mainly by Dubertret (1940, 1961, 1966), deVaumas (1954), Geze (1956), Combaz et al. (1961), Boulos (1962), Wright (1962), Emery and George (1963), Fleisch and Sanlaville (1969), Sanlaville (1967, 1970, 1977), Goedicke (1972), and Beydoun (1976). Although the history of the former islet of Tyre and the causeway built by Alexander's troops is fairly well known, a study specifically concerning its sedimentological and littoral aspects has not been done.

The historical city of Tyre consisted of the terrestrial city Palaetyrus (old Tyre) and the island fortress located about 1 km offshore. Because the main development of the tombolo connecting the isle of Tyre with the mainland was the direct result of human intervention, its historical background is crucial to a better understanding of the development of the site.

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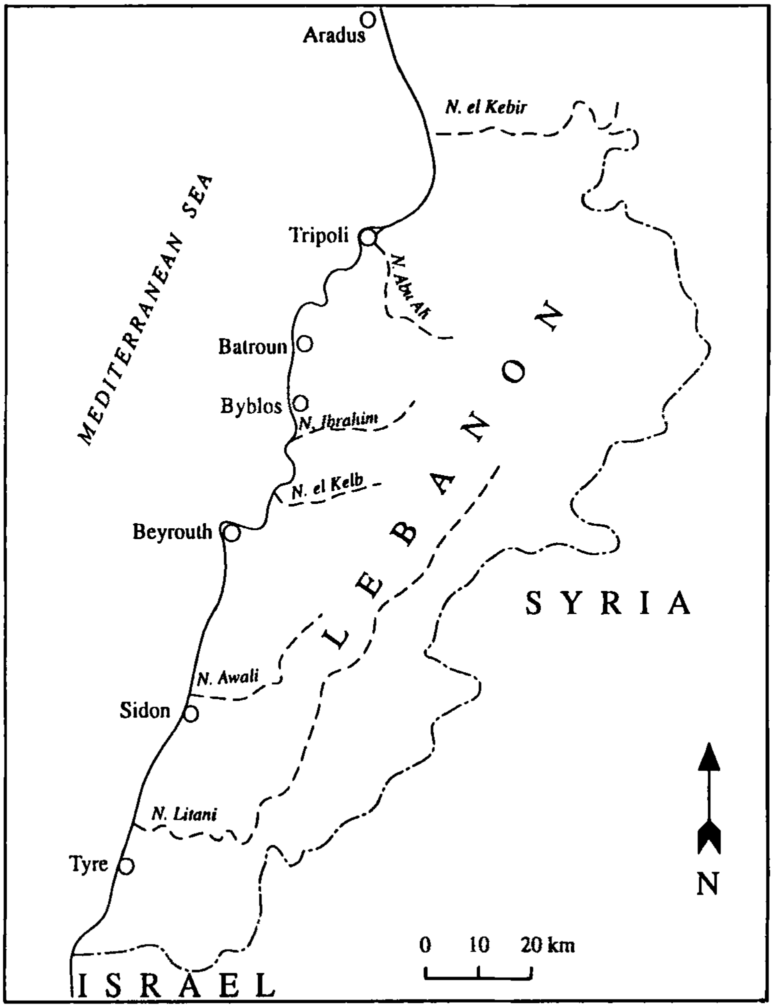

Figure 1. Location map.

HISTORICAL BACKGROUND

Tyre is one of the most famous Phoenician cities located along the eastern Mediterranean shoreline. Other cities were erected on headlands and islets close to the shore. The main cities were, from south to north, Tyre, Sidon, Berytus (Beirut), Byblos (Jebeil), Botrys (Batroun), Tripoli, and Aradus (Figure 1). The cities of Tyre, Byblos, Botrys, and Tripoli were built on offshore rocky substrate. Most cities possessed two ports, the northern port serving Phoenicia, or in Tyre's special case "Sidonia," and a southern port serving Egypt (Jidejian, 1969). The Egyptian harbor of Tyre was silted in later stages by natural agents and ceased functioning for this and other reasons.

The city of Tyre was the metropolis for numerous Phoenician colonies in the Mediterranean. For centuries Tyre served as the main commercial port of the eastern Mediterranean. There is no doubt that the twin harbors that existed both in Tyre and Sidon gave these cities a large economic advantage in the entire eastern Mediterranean commercial structure, as ships could find excellent refuge during either the main southwesterly or northwesterly storms in the respective harbors.

Tyre is known from both historical and archaeological records. Its first historical record is from the Middle Bronze Age (ca. 4000 yr B.P.). Tyre is also mentioned in a text of the Egyptian Middle Kingdom (3900–3600 yr B.P.), and later in the Tell el 'Amarna correspondence of the 14th century B.C.E. (Jidejian, 1969).

In the 10th century B.C.E., King Hiram, the son of Aviba'al, joined two islands by sealing off and filling the lagoons on which Tyre maritima was built, reclaiming a considerable area of land from the sea. The two harbors were enlarged and a canal connected them through the city (Josephus Book 8 147, after Dios). According to Sanlaville (1977:708), Hiram was the first to try connecting the isle to the mainland. A relief of the Bronze gates of Balawat built by Shalmaneser III (858–824 B.C.E.) depicts ships from Tyre bearing tribute to the Assyrian Monarch (Jidejian, 1969). The fact that the tribute was transported by boats and not overland proves that Hiram's causway either never existed or was later destroyed. The Assyrian emperor Esarhaddon (680–669 B.C.E.), who succeeded Sennacherib, described Tyre in his narrative as an island. In a literary text the prophet Ezkiel (26:8) describes Nebuchadnezzar's siege on Tyre which lasted for 13 years (585–572 B.C.E.) and the casting of mounds against the city. During this attack of Nebuchadnezzar on the isle, the citizens of Tyre, in order to avoid conquest, destroyed a mole, which has probably been a partially built causeway connecting the island to the mainland.

Renan (1864) states that most of the south facing Phoenician ports could not be found in archaeological surveys of the mid nineteenth century because they had been silted. As mentioned above, Nebuchadnezzar probably tried to restore the destroyed or partially constructed rampart. Jerome (in Fleming, 1915) suggests that Nebuchadnezzar may have constructed a mole, but Fleming doubts this, believing that the facts showed no reasonable probability that the mole was constructed before Alexander. About 200 years later, Alexander began his march (332 B.C.E.) toward the conquest of Persia, which commenced on the eastern Mediterranean coastal belt where the Persian fleet bases were located. All Phoenician cities, with the exception of the island of Tyre, the head city, surrendered to Alexander's army without a battle. Therefore, Tyre's position decided whether the Phoenician fleet would remain loyal to the Persians or would be controlled by Alexander.

Tyre, fortified with a 45-m-high wall at its eastern side (Fleming, 1915) and

Figure 2. Wide sandy beaches.

possessing a superior fleet, proved difficult to conquer. The refusal of the Tyrians to surrender led Alexander to connect the isle to the mainland with the construction of a causeway, one of the most difficult marine engineering tasks of that era. According to Quintus Curtius (first century B.C.E.) (4.2.7) (in Jidejian, 1969), a strait of 4 stadia long (186 m to the stadium, hence 744 m, a figure very close to the one found in maps), separated the city from the mainland. Plinius, on the other hand, despite having visited the site, mentions 3700 paces for this distance, a figure that equals some 2800 m or 5600 m, an enormously exaggerated figure. These straits were especially exposed to southwest winds and storms.

The Macedonians, with labor of additional people from neighboring inland communities, who were pressed into service, constructed a mole, which started on the mainland, near Palaetyrus (ancient Tyre), probably at the apex of the natural small tombolo. The stones of the fresh ruins of ancient Tyre, together with trees limbs, were drawn into the water, and stones and sand were placed on top of them in order to build the mole. Timber from the mountains was also used for the construction of rafts and towers, as well as fixing stakes in the sediment. This mole was planned to terminate on the eastern shores of the islet of Tyre.

In its first stages the construction was quite simple and proceeded with practically no difficulties in the shallow water. However, once construction reached deeper water the Tyrians made the construction of the mole impossible for the Macadonian soldiers by pulling up the stakes that protected the face of the mole. The heavy sea that accompanied the wind swept all the work away. There was also a natural barrier consisting of the channel between the mole and the island, which resulted in currents that washed out the incipient causeway. As a result of the natural and human obstacles to the causeway's completion, for the final section of the causeway Alexander decided on a new and wider mole, inclined somewhat towards the southwest, which would not have a full side exposed to the winter storms on one hand, and avoid, as much as possible the closeness to the Tyrian fighters on the other.

Arrian 2.18.36 (in Jidejian, 1969) estimates the deeper parts of this causeway to have been "three fathoms" (ca. 5.5 m) in depth. It should be recalled that the historical sea level of the Hellenistic period was about 1.2 m lower than during Roman times and the present (Nir and Eldar, 1987). Only after achieving sea supremacy by the addition of the rest of the Phoenician and Cyprian fleets could Alexander protect the mole workmen, who then finished this gigantic project. Toward the end of the battle of Tyre, after a siege of 7 months from mid-January of 332 to mid-July of 332 B.C.E. (Fleming, 1915), the Macedonians succeeded in extending the mole to the city wall, thus connecting the mainland with the fortified islet. In order to further strengthen the mole, Alexander (Diodorus of Sicily, first century B.C.E., 17.40.5, in Jidejian, 1969) demolished parts of the newly conquered city and ordered thousands of workers to widen the mole with its stones. In its last stage, the mole reached an average width of 200 Greek feet (about 60 m). After Alexander's conquest, Tyre became a peninsula through the quick accumulation and deposition of a huge sand tombolo along the mole both on land and underwater.

GEOLOGICAL DESCRIPTION OF THE SOUTHERN COASTS OF LEBANON

The Plain of Tyre stretches along the southern Lebanese coast from the Israel–Lebanon border to the south, and north 25 km to the mouth of the Litani River (Figure 1). This is one of the widest sections along the coastal plain of Lebanon alternating in width from a few hundred meters (Figure 2) to 3 km. A series of headlands, consisting mainly of Cenomanian dolomitic limestone and chalks, reach the sea and protrude into the shallow waters, creating natural barriers for littoral drift. As a result, this drift is limited to relatively short littoral cells in between these headlands. Many sea cliffs, different in elevation and relief from the Cenomanian cliffs, are found along southern Lebanon coast. These cliffs are composed of alluvium and cemented eolianite ("Hajar Ramli") (Dubertret, 1940), which are presently eroding at a very high rate. Emery and George (1963) suggest that this erosion has been accelerated in modern times, a conclusion that results from the existing histori-

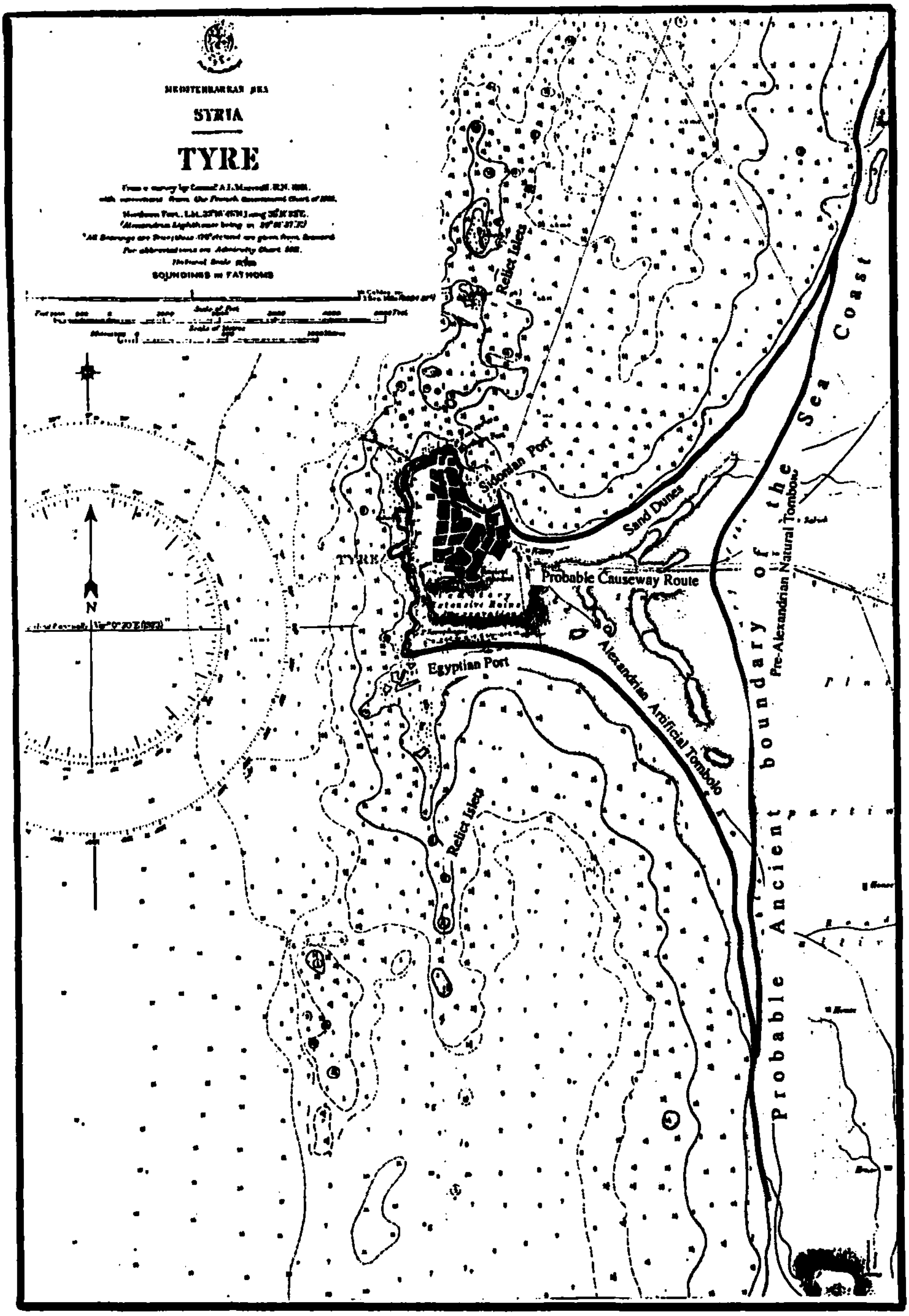

Figure 3. Mansell's map.

cal shore sites, which otherwise would have disappeared by now. Recent observations of these beaches show that a very high percentage of the coastal sand was removed for construction purposes, exposing the beaches and their backshore to more energetic wave action.

South Lebanon coasts are oriented in a SSW to NNE direction. Many of the beaches are very narrow, hardly reaching a few dozen meters. In some regions the mountains descend directly into the sea and form natural barriers for littoral drift. As a result, the Lebanese coasts are composed of multilittoral cells, independent in components, which do not affect each other. Neighboring beaches, therefore, may differ in coastal components such as mineralogy and grain size. Before the construction of the causeway the coasts opposite Tyre were exceptionally wide. This physiographic feature resulted mainly from deposition of a semi-tombolo on the shoreline opposite the Tyre islet and its additional underwater rocky relicts.

Primary Sediment Sources

(1) The sediments of the mountainous crest of Lebanon are transported to the beaches by the rivers mainly during winter floods. The main supplier of sediments to the Tyre plains is the Litani River (known as Nahr Qasmiye in its upper section), the longest Lebanese river (150 km), which drains some 8 km north of Tyre. The sandy formations found in the mountainous stratigraphic column belong to Lower Cretaceous sandstones (base Aptian "Gres de base") and contain quartz grains of granitic source. These are present mostly on the eastern and southwestern flanks of Anti-Lebanon Mountains (Dubertret, 1940; Geze, 1956; Combaz et al., 1961).

(2) Quaternary sediments:

(a) Coastal ridges known as "Hajar Ramli" and their derivative sands are found along most of the southern Lebanon coasts. These sands are very rich in carbonate content (Dubertret, 1940; Emery and George, 1963). The erosion of these ridges supplies the beaches with large amounts of calcareous sand. At present, one should also take into consideration the aformentioned fact that a very large quantity of Lebanon's beach sands were mined and removed, leaving rocky, denuded beaches.

(b) Sand dunes developed along the Lebanese coast. However, the intensity of dune building has been very low in comparison to the littoral sand dunes of Egypt, Sinai, or Israel, which originate from the Nile. Most of these dunes that originate from mostly local resources were either removed and mined for construction purposes during the past few decades or covered by construction. At present almost no sand dunes are left along the south Lebanon coasts. Sanlaville (1977) divides the dunes into two different sections: fossil and recent (Holocene). The dunes are richer in quartz grains than the beach sand, which contains many more components of biogenic origin. Some low relief sand dunes found on the Tyrian

Figure 4. Oblique aerial photo.

tombolo were mapped by Mansell in his bathymetric chart (Figure 3), features that have since disappeared.

(c) Sandy red soil, found mainly south of Beirut, contains a mixture of quartz grains and red clayey soil. The eroded red soil also supplies quartz grains to the system. The mineralogical composition of the sand in and around Tyre's coasts shows that the main constituent is $CaCO_3$. Analyses of nine samples from Rashidiya in the south to northern Tyre made by the author show an average of 80% $CaCO_3$. Earlier Sanlaville (1977) found a somewhat smaller carbonate content for the same region (65–70%). The Litani River outlet beaches found to the north are much poorer in $CaCO_3$ (18–35%). The $CaCO_3$ concentration in the sediments of the southern section of Tyre's tombolo reflects some sorting through transport. The fact that the present Tyre beaches are composed mostly of carbonates leads to the conclusion that most of the tombolo (about two thirds or more) is composed of redeposited local grains of the so-called "Hajar Ramli" belonging to the Quaternary calcareous sandstone, which probably covered quite large areas in the past.

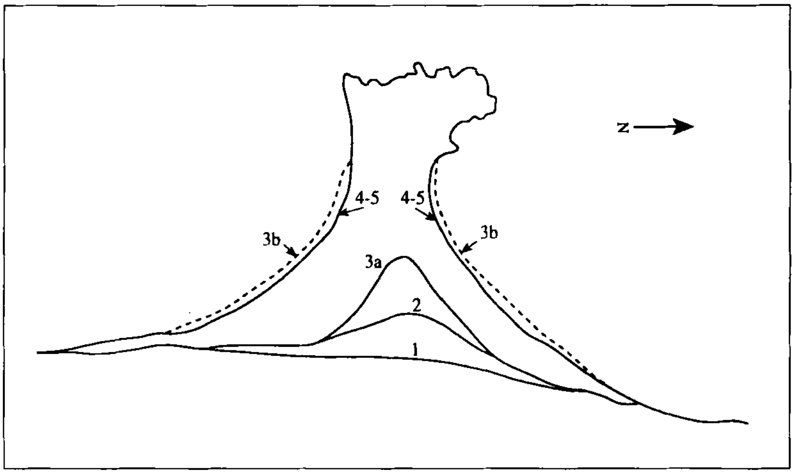

Figure 5. Old shorelines of Tyre's peninsula. (For legend see Table I.)

THE DEVELOPMENT OF THE GIGANTIC TOMBOLO

The islet of Tyre, in its natural condition, is composed of an elongated calcarenitic sandstone ridge (Hajar Ramli), the relicts of which are the present low relief rock islet upon which Tyre is built, and its tiny rocky satellites (Figure 3). A wide abrasional platform of biochemical origin lies to the west of the main islet (Figure 4). A succession of primarily submerged rocks extends 2500 m from the southwestern extremity of the island. A few rocks near the island emerge above sea level. Four tiny islets are also found north of the northwestern extremity of Tyre up to 1500 m from this point. Some of these platforms and small islets were used as sources of building stone for the famous Tyrian masons.

Weather data from Beirut shows that the predominant winds are from the south, southwest, and west, while the north, northeast, and east winds are weaker and much less frequent (Sanlaville, 1977). These dominant directions show a similarity to the wind regime of northern Israel. South Lebanon beaches are open to storms reaching from 250° with a maximum fetch of 450 km and up to 300° with a fetch of 650 km. The longest fetch reaching southern Lebanon is from 280° and is about 2400 km, while the 265° direction is 1900 km long. These directions match the direction of the main storms of the Levantine Basin. The pattern and shape of the low relief sand dunes that existed on the tombolo (Figure 3) up until their disappearance under built-up areas show very clear SW–NE and NNW–SSE elongatd dunes corresponding to the main wind directions. The existence of northern and southern harbors, as opposed to a single harbor in some other Phoenician coastal cities, was necessitated by the occurence of both southerly and northerly storms, resulting in the above-stated sediment transport from both directions.

The present city of Tyre is found in the central and northern parts of the former islet, while the Roman city and probably also the Hellenistic city were built on the southern section. This situation may have been the result of the greater protection of the southern zone from southwesterly in the past. This protection could have been provided by natural rocks that have since been eroded and/or quarried, or by an artificial sea wall or breakwater.

Due to the fact that the southern Lebanon coast is oriented SSW to NNE, the major winter littoral drift should be toward the north. Northerly and northwesterly winds are responsible for the southerly directed littoral drift, which is estimated to be less effective than the northerly one. Due to the existing special conditions around Tyre, however, for the past 2300 years, all sands transported toward Tyre either from the north or from the south have been captured and trapped in the tombolo. There is insufficient data to estimate the length of time it took for the tombolo to reach maturity (i.e., some type of equilibrium between incoming and outgoing sands). Small, artificial, detached breakwaters close to shore located near "unlimited" sand sources usually reach equilibrium in a few years (Nir, 1982). With this special case, however, the amount of available sand was limited due to the natural conditions of the Lebanese coasts. It seems that the big sand reserves drifted toward the tombolo in a short time. Since that time, the regular sand drift towards the tombolo has been very small. Although there is no doubt that some of the sand accumulated on land through loss to aeolian agents, the majority of the wind-driven sand returned to the system via longshore drift. As a result, the net northerly sand drift, which should have resulted in an asymmetric tombolo, as is the case in many other coastal sites, was to a great extent masked, as exhibited by the present practically symmetric tombolo.

Kenrick (1855) published the first modern map of the peninsula with an "isthmus of loose sand accumulated over the Mole constructed by Alexander." The outlines of the city of Tyre were quite accurate, but the shape given to the tombolo's shorelines is unfamiliar. Later, Renan (1864) mapped the region, as did Mansell (1861, in Anonymous, 1939). Renan's (1864) map shows some asymmetry in that the southern lobe is somewhat larger than the northern section of the tombolo.

The 1:16,200 scale bathymetric chart (Anonymous, 1939) was studied in order to estimate the size of both the pre-Alexandrian small semi-tombolo that should have existed and monitor the development of the additional parts that have connected the land with the islet since Alexander. This map, based upon a survey done by Commodore A. L. Mansell of the British Royal Navy in 1861, was drawn before the beaches and the tombolo around Tyre were altered by modern development (e.g., construction, sand quarrying). One of the most important differences between this map and the modern topography is the shoreline opposite Tyre. Mansell (1861, in Anonymous, 1939) described a "probable ancient boundary of the sea coast," a morphological unit discernable at the time of the mapping, but which has since totally disappeared (Figure 3).

The offshore regions included in the inner waters between Tyre and the coast (Figure 3) south and north of the peninsula differ in depth. The southern offshore region is deeper than the northern. This asymmetry could have resulted from the higher effectiveness of the net northerly directed drift that bypassed west of the islet of Tyre. This larger sand accumulation on the northern side, which resulted in shallower bathymetry, could have also be a direct result of greater southerly sand transport from northern beach sources. This drift occurred along a narrow rocky strip of shallow water just west of Tyre (Figure 4), which facilitated sand transport.

The land area of the original, natural semi-tombolo which protruded some 500 m offshore (Figure 3), and started to develop during the last post-glacial sea level stabilization some 6500 yr B.P. This semi-tombolo was influenced and created by the "shadow" of the barrier formed by the island of Tyre and its tiny satellite reefs to the north and to the south. The area of this primary-old semi-tombolo was, according to this map, about 670,000 m^2.

The additional younger post-Alexandrian tombolo, which formed mainly as a result of the causeway, acted as a huge barrier groyne, accumulating a 1,600,000 m^2 tombolo in the waters between the natural semi-tombolo and the islet.

The newly built groyne (causeway) practically stopped entirely the northerly and southerly directed littoral drift in that particular region. All the sediments that reached the tombolo area were protected by the islet and its satellites. The sediments were then deposited in an ever growing tombolo, until at a certain stage, it reached the islet of Tyre. The 23 centuries which have passed since the construction of the mole have totally destroyed all traces of both the stages of accumulation that might have enabled identification and the follow-up after ancient shorelines and/or the direction of net longshore drift. The present morphology of the tombolo represents the total sum of available sand in the system, which no doubt reached equilibrium many centuries ago.

Due to the fact that only three stages of the aerial and quantitative development of the tombolo are known (stages 1, 2, 3a, and 4 in Figure 5), it is somewhat speculative to try to describe the various stages starting from pre-Alexandrian stage to the period when sedimentological equilibrium achieved, either a few hundred years or more than thousand years after Alexander. Table I provides a summary of the expected stages of the causeway construction and the subsequent sedimentological stabilization (also see Figure 5).

Nir (1982) provides a formula for the quantitative development of artificial tombolos accumulated along offshore structures in the eastern Mediterranean sandy beaches. The main components are the relationship between the distance offshore of the structure from the original shoreline and its length parallel with the shore. If this ratio is 2.0 or more, practically no significant sand

TABLE I. Expected stages of the causeway construction and sedimentological stabilization.

Stage, Time, and Historical event	Sedimentological Development
1. Around 6500 yr B.P.	First stages of primary natural semi-tombolo, development of sand body to boundary given on Mansell's map (2)
2. January 332–July 332 B.C.E.	Some sand accumulations near root of causeway
3. 331 to Roman Period (Rise in sea level of about 1.2 m)	The longshore transport across the Tyrian coast totally ceases. Higher rate of sand accumulation on both sides of causeway. Towards Period (4), rise in sea level, causing partial cover by sea of the tombolo
4. Roman Period to ?	Slow rebuilding of tombolo to its former size (3b). Slow accumulation of sand on both sides, deposition rates directly depend on longshore transport capacity and availability of sand. Sedimentological equilibrium at the beginning of period(?)
5. ? to Present	Sedimentological equilibrium, with small yearly seasonal changes of erosion and accretion on coasts of the tombolo. Some of the sand moves from coast and accumulates in shallow dune fields on the tombolo and inland

accumulation will occur. The specific conditions of Tyre show a 1500/1000 m ratio of distance offshore to the Holocene shoreline (which stabilized some 6500 yr B.P.) to the length of the islet (see Figure 5). This ratio of 1.5 and the additional satellite reefs to the north and south of the islet that protect and "shade" the shoreline were the main cause for the original pre-Alexandrian small semi-tombolo (Figure 3). There is no doubt that this original semi-tombolo, as well as all other sand bodies of this type, had a vast underwater continuation that has, in this case, affected the entire bathymetry between Tyre and the mainland. Sand volumes (V) of the huge "combined" Alexandrian tombolo were calculated according to formula suggested by Hall for trapezoid tombolos (J. K. Hall, pers. comm., in Nir, 1982):

$$V = dc(2a + b)/3$$

where 2a is the length (m) of the tombolo's offshore edge (taken parallel to the shoreline), b is 1/2 of the length (m) of the base of the tombolo, c is the distance (m) between the base and the seaward edge of the tombolo, and d is the water depth (m) at the seaside edge of the tombolo.

Based upon the present depths found 1500 m offshore some 5 km south of Tyre, it is suggested that compilative water depth near the eastern limit of

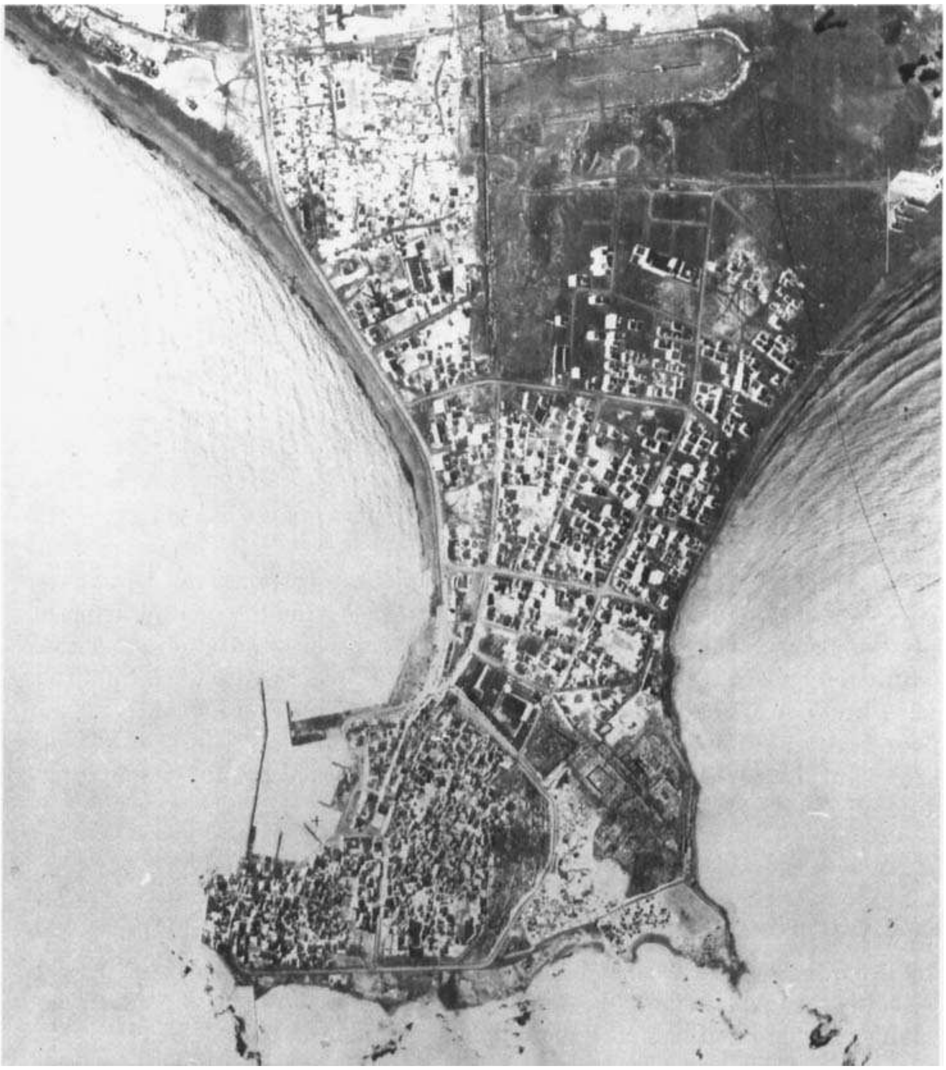

Figure 6. Vertical aerial view of Tyre, 1975.

the islet, at the location where the tombolo reached Tyre, was around 5–6 m during the Hellenistic period, with a rise in sea level of ca. 1.20 m toward the Roman time, reaching ca. 7 m in depth. Calculations based upon the above formula, for an average depth of 7 m at the seaside edge of the pre-Alexandrian time islet, result in an estimated volume of some 8,400,000 m^3 for 0 m level (each meter difference in bathymetry will change the total volume in ca. 1–2 million m^3). To that figure we must add the present 3.5 m average elevation of the tombolo's area (von Werner, 1975). It also seems therefore that a few more millions of cubic meters of sand should be taken into account in the calculation of the volume. The causeway built by Alexander's troops as reported by many past historians, was 60 m wide. Therefore, an average volume of $60 \times 1000 \times 4 = 240{,}000$ m^3 should be subtracted from the major figure of more than 8 million m^3. There is no doubt that some sand accumulated naturally near the newly built causeway during the construction period of 7 months, and the 240,000 m^3 mentioned was not all imported artificially by the Macedonians and their slaves.

The average yearly quantity of sand accumulated since the causeway was built up to mid-nineteenth century mapping by Mansell, a period of some 2200 years, is about 4250 m^3. Both the southern and the northern sections transported a volume of 2100 m^3/year each. These figures do not take into consideration the additional volume of underwater sand at the outskirts of the tombolo, which may have been considerable. These estimates of the yearly average rate of sand accumulation could be too small, and the actual historical supply has been much larger—minimizing the sand accumulation time until the adult tombolo built, a stage that was probably reached in a few hundreds of years, and not in 2000 years, as suggested above. This problem of "construction" or accumulation-time will, of course, be obscured until further studies, and relevant data will be discovered either in historical documents or in the field itself.

CONCLUSIONS

The huge tombolo of Tyre is some 2300 years old, and is the direct product of the causeway constructed by Alexander's troops. Prior to this act, there had been an embryonic tombolo, the result of the island of Tyre and the two chains of satellite islets to the north and south of the island. Prior to that stage, when sea level stabilized at around 6500 yr B.P., the primary shoreline was further inland, a straight continuation of the present trend of this part of southern Lebanese beaches (Figure 5, stage 1). Soon after stabilization, and probably some time prior to this stabilization, the primary tombolo started to accumulate. This primary tombolo existed more or less in the same aerial distribution until the causeway was constructed.

The further stages of increase in the tombolo's size are well seen in Figure

5, which, in a schematic way, represents the extreme borders during each period of its existence. There is no doubt that, during the 1.20 m sea level rise from the Hellenistic to the Roman period, there was a decrease in the area of the Alexandrian tombolo. Therefore, the present size is a further development that started during sea level rise since its stabilization in Roman times. More sand was added to this complicated system from either aeolian erosion of the nearby landmass, longshore drift from nearby beaches, or both.

In conclusion, the case of Tyre shows the effect of cultural events on the surrounding landscape. In the case, the development of the enormous tombolo resulted from the refusal of the citizens of Tyre to surrender to Alexander the Great.

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