Hvide Sande Inlet, Denmark

PART IV

COASTAL, ESTUARINE, AND ENVIRONMENTAL PROBLEMS

Ferring Lake, Denmark

CHAPTER 119

ANCIENT AND MODERN HARBORS: A REPEATING PHYLOGENY

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ABSTRACT

The Minoans and Phoenicians appear to have developed a very superior "lay" understanding of waves and currents, which led to the development of remarkable concepts in working with natural forces in their coastal engineering works. For example, the Phoenicians developed a "continuous self-flushing" harbor at Tyre and possibly a "flushable" harbor for the removal of sand and silt at Sidon. It would appear that developments of this type were the outgrowth of the close association with and acute observation of nature that occurs where a coastal people learn to work with currents and sail, in the absence of technology for harnessing large amounts of power. However, harbor design became markedly stereotyped following the development of large engineering corps with the capacity for rapid and massive construction. The earlier innovative, natural concepts in harbor design appear to have become obscured by the end of the Roman era, and have remained relatively unused to this day.

In view of man's present extensive intervention in the coastal zone, mostly based on "brute force" technology, a careful study of the ancients' ability to work with nature provides valuable insight for today's problems.

INTRODUCTION

Maritime activity began in the Mediterranean Sea about 4,000 years ago. It is here that the first rudimentary sea-going ships appeared, which in time led to the development of significant maritime commerce and the associated technology for building docking facilities and harbors. The evolution of marine technology, its adjustment to man's socio-economic needs, and the impact of natural catastrophies, are all recorded in the remains of sunken ships and the ruins of the many ancient harbors that border the Mediterranean Sea (Figure 1). Fortunately, a number of excellent treatise on ancient ships, harbors, and cities in the Mediterranean have been published (e.g., Casson, 1959; Flemming, 1969, 1971).

It seems that the earliest mariners landed and beached their boats. They also used the natural protection afforded by rivers, headlands, and embayments to moore and anchor in protected waters. The numerous small islands of the Aegean Sea were ideally situated for protecting early mariners. However, as ships became larger and their number increased, the development of docking and harbor facilities became essential. It is apparent that by 1500 BC the Minoans were constructing protected wharfs

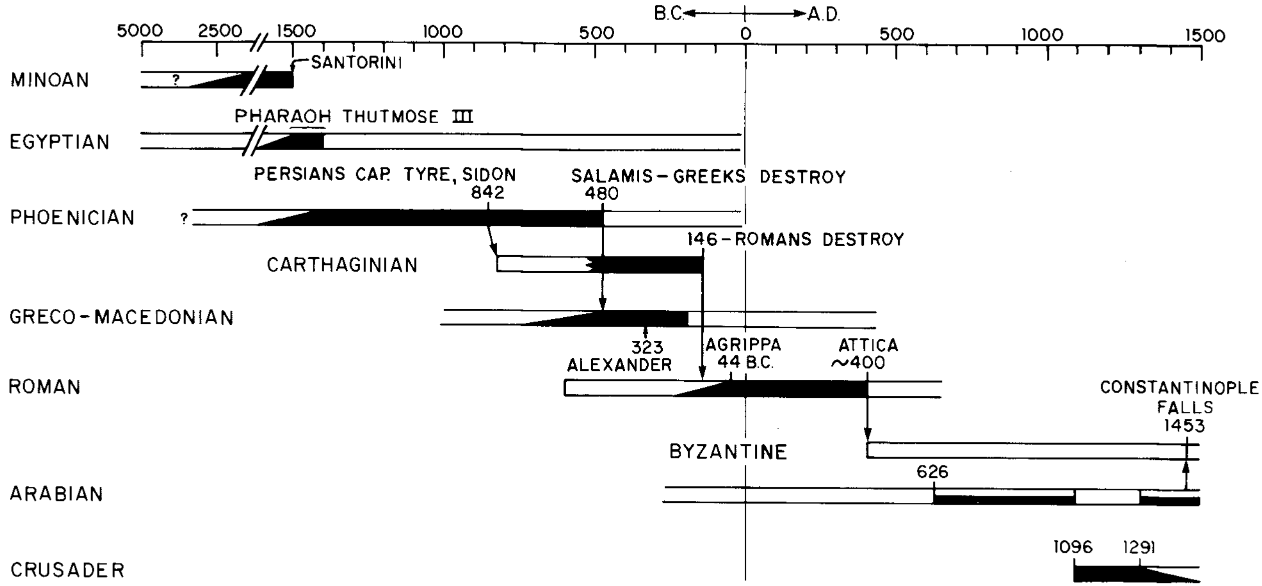

Figure 1. Chronology of civilizations' influence on Mediterranean harbors and ships.

and berthing facilities by excavating them into the sandstone rocks at Nirou Khani, Crete. The perfection of protected anchoring basins with quay-side berthing facilities appears to have been a Phoenician development as illustrated by harbors at Sidon, Tyre, Akko (Acre), and Atlit along the coasts of Lebanon and Israel.

The present location of ancient harbor sites is markedly influenced by sea level changes, coastal tectonics, and the erosion and depositional history of the coast. Sea level has risen at rates of about 10 to 15 centimeters per century during the past 3,500 years, leading to what would appear to be a submergence of the coastline relative to sea level of about 3 to 5 meters. In the absence of other factors,one can expect to find that ancient harbor sites are submerged, and indeed a large number of them are (Flemming, 1969b; 1971). Coastal tectonics may accelerate this effect by submerging the coast, or alternatively,decreasing the submergence or completely overcoming it by raising ancient sites above present sea level. Finally, erosion and deposition alter the coastline so that ancient sites may now be far at sea, or buried some distance inland from the present shoreline. The latter case is typical of coasts where rivers have prograded the shoreline and filled former embayments. Typical examples of landlocked sites are Luni, Aquileia, and Ostia in Italy (Figure 2).

MINOAN HARBORS

The Minoans were the first people to whom history ascribes an extensive maritime commerce and a navy. They conquered and colonized the Isles of the Aegean, and through their fleet maintained control over much of the eastern Mediterranean from prehistoric times to 1500 BC. Principal centersof Minoan civilization appear to have been on the islands of Crete and Thera (Santorini), thus protecting them from invasion, except by sea. Their ships protected the islands and therefore their cities needed no stone walls (Casson, 1959).

The Minoan dominance of the Mediterranean appears to have ended abruptly in 1500 BC with the explosion of Santorini volcano and the subsequent tsunami that destroyed the major Minoan cities (Figure 3). It seems that the Minoans were about to embark on war with Egypt and Greece when the Santorini explosion intervened, demolishing the Minoan empire and causing extensive damage in Greece and Egypt (Galomopoulus and Bacon, 1969, p 19; Chadwick, 1972). In excavations near Heraklion Crete, Marinatos (1926) found buildings filled with pumice and ash, and in one instance found where massive blocks from a Minoan wall had been moved over 18 meters, apparently by catastrophic wave action.

The explosion of Santorini was far greater than the eruption of Vesuvius that destroyed Pompeii in 79 AD,and several times more powerful than the explosion that destroyed Krakatoa in 1883. The Santorini explosion blew out 83 square kilometers from the center of the island,and formed dense ash clouds whose deposits are now found as volcanic ash layers in sea floor cores from the eastern Mediterranean (Figure 3).

Thus, it appears that a great sea empire vanished almost overnight. This event made a vivid imprint on the minds of the Mediterranean peoples.

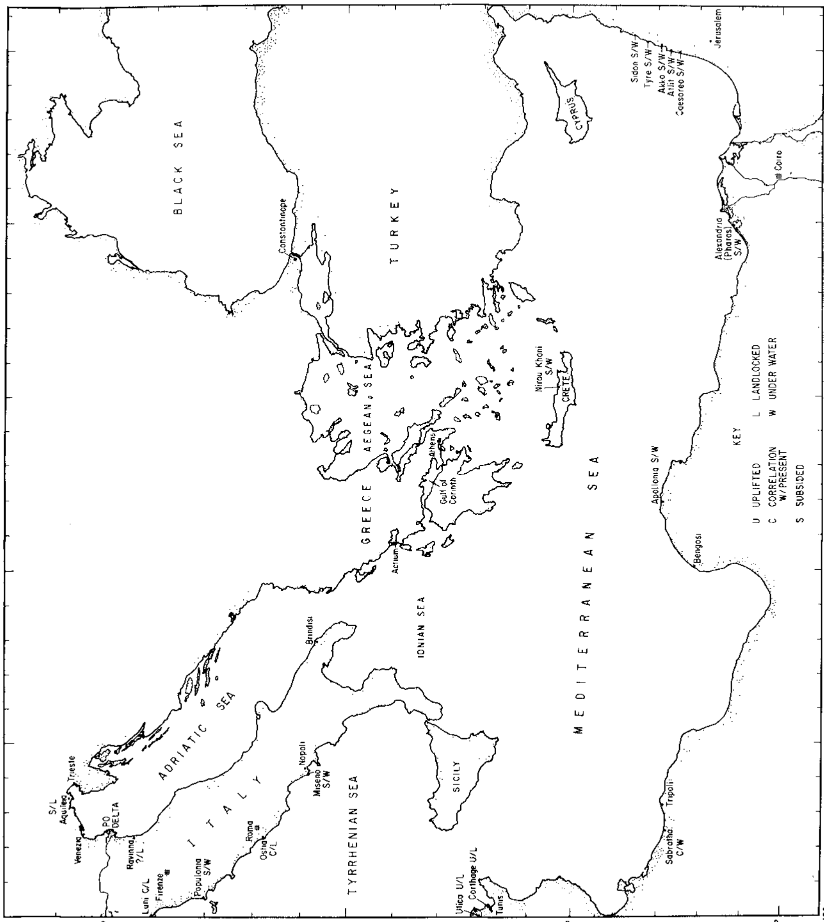

Figure 2. Some ancient harbor sites in the eastern Mediterranean.

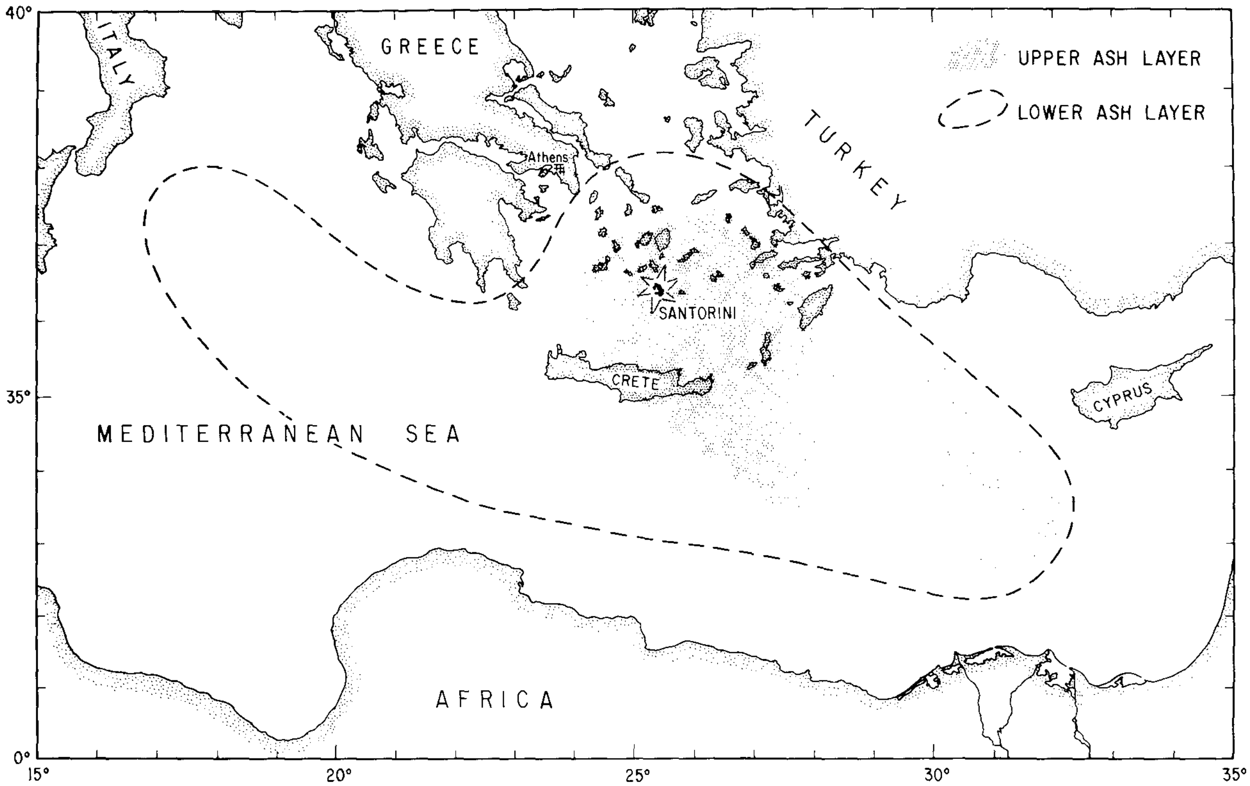

Figure 3. Extent of the distributions of two deep sea layers of volcanic as from explosion of Santorini volcano. The lower ash layer is older than 25,000 years, while the upper ash layer appears to correlate with the explosion of 1500 BC that coincides with the decline of the Minoan civilization (after Nickovich and Heezen, 1967).

Plato, who traveled extensively in Egypt as well as Greece, appears to have used the legend of a lost civilization on a continent sinking beneath the sea as a setting for his Timaeus and Critias. Thus, about 360 BC Plato recorded for posterity the myth of Atlantis (Mavor, 1969, p 12).

The principle harbor for the city of Knossos on Crete was probably at Amnissos,near the present harbor of Heraklion. This has been largely destroyed or covered by subsequent structures. An ancient sea port was established near Heraklion by the Saracens in the 9th century BC. This was rebuilt and fortified by the Genoese in the 9th century,and enlarged and strengthened by the Venetians in the 12th century. The Venetian harbor remains as the inner basin of the modern harbor of Heraklion.

The first harbor that dates from Minoan times was found at Nirou Khani about 12 kilometers east of Heraklion (Marinatos, 1929). It consists of several slips cut into the dune rock of the small headland forming the western end of the beach fronting the Knossos Beach Hotel (Figure 4). In plan, the major excavation consists of a single rectangular cut,43 meters long and 11 3/4 meters wide,with a masonry rock wall 3/4 meters thick running the entire length of the excavation and dividing it into two long channels 6 x 43 meters and 5 x 43 meters. The excavation is on the sheltered lee side of the headland,and is associated with numerous walls that are both parallel and orthogonal to the excavation. On the landward side of the excavation is a 6 meter wide level area as though it had formerly been a wharf.

Both the wharf area and the masonry wall are now near sea level or 10 to 20 cm above sea level. Thus, it seems that the sea has risen at least one meter relative to land since the Minoan wharf was built. The excavated portion of the tank has a sand bottom with a maximum depth of 2 meters below sea level, but the excavation and wall appear to go deeper than this. The northwest or windward side of the headland contains a quarry area which appears to have been used for obtaining stone for the structures now found on the lee side.

It is of interest to note that the two harbor berths at Nirou Khani, which are 43 meters long by about 6 meters wide,would easily have accomodated two of the well known Greek trireme of a later age. The trireme is reported to have had a length of 35 meters, beam width of 3.7 meters, and a draft of 1.1 meters (Galanopoulos and Bacon, 1969, p 129).

PHOENICIAN HARBORS

Initially the Phoenician civilization occupied what is now roughly Syria, Lebanon and Israel. The Phoenicians were one of the great peoples of the world and were noted for their sailing, navigating, trading and colonizing. The alphabet of the western world, as well as the Greek and Roman alphabets, were derived from that of the Phoenicians. The Phoenicians were well known to the Egyptians as early as 2900 BC, but it wasn't until about 1400 BC, following the fall of the Minoan empire,that they became a great sea power.

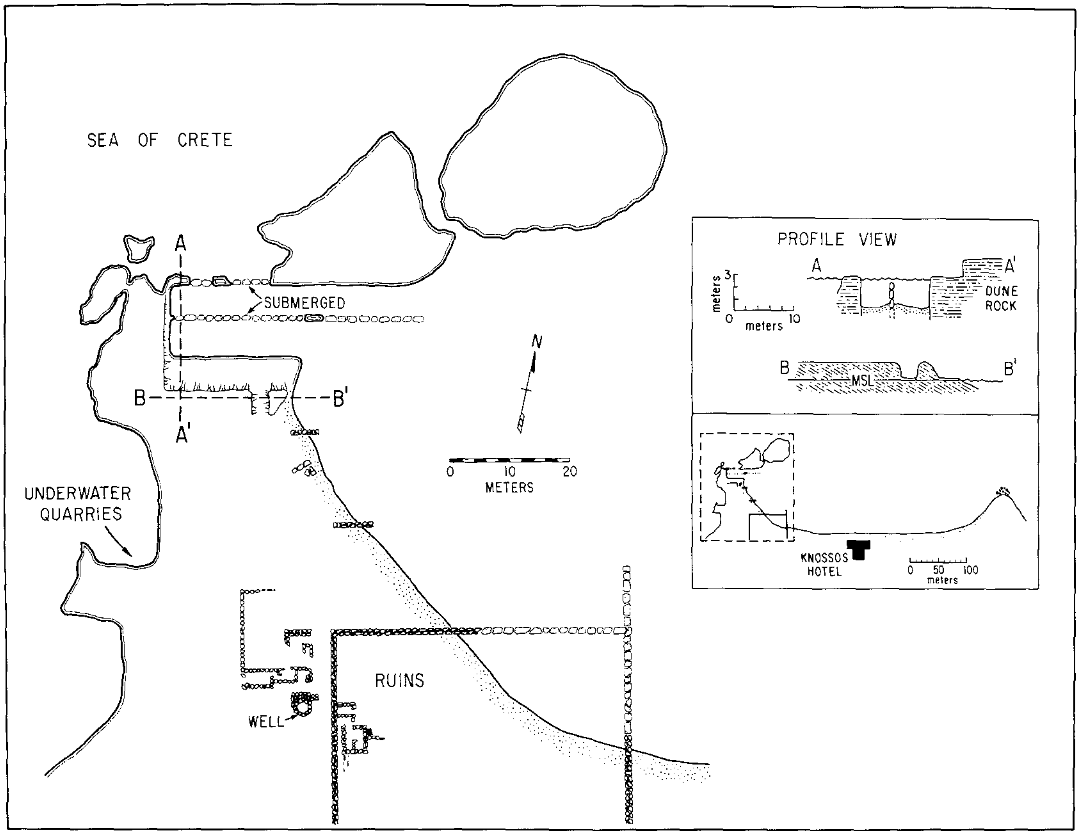

Figure 4. Minoan harbor and market place (circa 1500 BC) at Nirou Khani, 12 km east of Heraklion, Crete. Details of the two 40 m long harbor slips measured by author in October 1972; archaeology from Marinatos (1926).

In 1500 BC Phoenicia became a frontier province of Egypt and by 1400 BC had regained independence. It remained at the height of its power and influence for the next 400 years. From 1200 to 800 BC the Mediterranean became a "Phoenician Lake". The Phoenicians established colonies along the African and Spanish coasts of the Mediterranean and along the Atlantic coast of Africa and Portugal. Their decline as a world power began in 842 BC when the Assyrians captured the principle Phoenician cities of Tyre and Sidon. However, they remained a great naval power under Persian rule until the fleet was destroyed by the Greeks in the battle of Salamis in 480 BC. Phoenicia came under Greco-Macadonian rule in 323 BC when Alexander the Great took Tyre and Sidon and destroyed the Persian Empire. Later,in the first century BC,the Romans seized Carthage, and Tyre and Sidon also fell to Roman rule. Tyre and Sidon remained Roman centers of learning and continued to prosper until the area fell to the Moslem invasion in 626 AD.

Probably one of the earliest Phoenician harbors was constructed more than a milenium BC in the Naaman River, and is now buried under a portion of the City of Akko (Acre) in Israel. The increasing importance of Phoenicia as a maritime people, however, soon led to the development of protected harbors with large anchorages and elaborate piers and quays for handling cargo. The well preserved ruins of the ancient harbors of Sidon, Tyre, Akko, and Atlit provide ample testimony to the high development of harbor engineering by the Phoenicians. The harbor of Tyre was originally separated from the mainland, and was considered to be self-flushing. The present tombolo connecting the harbor to land was constructed by Alexander the Great during the seige of Tyre in 323 BC. It is claimed that large reservoirs were built into the harbor of Sidon so that it could be flushed by opening sluice gates (Frost, 1963).

The harbor of Akko is the best example of a Phoenician harbor that has survived, with almost continued use, to the present (Figure 5). The original Phoenician base for the breakwater and lighthouse is still available for inspection by divers. Upon this foundation, and clearly identifiable by the unique construction techniques of the various civilizations, one recognizes the efforts of Hellenic, Roman, Crusader, and modern engineers.

The following description of the southern breakwater and the Tower of Flies (lighthouse) is based on a diving reconnaissance by me lead by Abner Raban,and the written account of Elisha Linder (1971). The breakwater closes the natural harbor and forms excellent protection from the frequent storms from the southwest. The south breakwater originally had a length of 340 meters, a width of 12 meters, and its base is on a sandy bottom. It is constructed of 4 layers of stone, the lower of which is Phoenician and is now 2.8 meters below sea level. The Phoenician and Hellenic layer above it are built in the "rashin" manner of cut stone pieces, about 0.6 x 0.6 x 1.5 meters in length. The Roman construction, which extends from just below sea level to about 1.5 meters above,consists of massive cut sandstone pieces, 2 x 2 x 12 meters in length, typical of the construction blocks used in the time of Herod the Great (73-4 BC). The Crusader layer,above the Roman,consists of cut stone pieces, about

Figure 5. Air photograph of the harbor at Akko (Acre) looking northwest. The modern rouble mound breakwater lays on a submerged foundation of Phoenecian, Roman, and Crusader construction. The submerged Arab breakwater dates from 900 A.D.

10 x 20 x 20 centimeters, that form a wall which was backfilled with rubble. The modern (highest) level consists of a large size rubble mound placed randomly on top of the ancient breakwater (Figure 5).

The Tower of the Flies is also known as El Minara, "The Tower of Light". Its lower construction is similar to that of the south breakwater except that it rests on natural rock. The lower level consists of elongated stones whose dimensions are 0.6 x 0.6 x 2 meters. It is built by the same method of "rashin" which makes up a line of stairs that starts at the natural rock bottom,which is at a depth of 5 1/2 meters.

The remnants of a submerged rubble mound breakwater are visible between the Tower of Flies and the shore. This was placed about 900 AD by the Arabs who sunk barges loaded with stone.

The tops of the breakwater and quay of the Phoenician harbor of Atlit are now just at sea level. They are constructed of very uniform rectangular cut stone pieces with dimensions of 0.4 x 0.4 x 1.4 meters. The stone slabs are offset and interlocked where the breakwater joins the quay wall (Figure 6).

The Phoenicians achieved a very high level of technology for submarine construction. The Phoenician stones are relatively small and don't have the lead connection used during Roman periods, or the iron connections which were used during the Crusader times. We do not know the methods they used to place the stones underwater, nor how they positioned and assembled the stones into the smooth walls which have withstood the effects of waves and currents for 25 centuries.

ROMAN HARBORS

The Roman Age began about 600 BC when the Etruscans began domination of much of Italy. In 509 BC,the last of the Etruscan kings were overthrown and Rome became a city-state and then a republic. It flourished and grew on previous and contemporary Greek teaching and thinking. The Greeks were the thinkers and the Romans were the doers. Originally, Rome was not a sea power, but became one in 260 BC during the Punic Wars (against Phoenicia) when Rome interferred with the affairs of Carthage, a Phoenician colony. It is reported that Rome became a naval power by making 100 copies of a Cartheginian warship in 60 days (Casson, 1959, p 159).

Early Roman harbors were carefully planned and well constructed. A good example is the port of Aquiliea which was built in 181 BC as an outpost on the northeastern frontier. Aquiliea was a river harbor designed to take ships about 35 meters long. It was unique in that its quays had two loading levels, one for high and one for low water levels (Figure 7). The mooring ports are constructed of three beautifully cut stones, morticed together with metal straps to form a round opening (Figure 8). It is not clear whether the opening was intended for a bollard to be used in mooring, or for a davit used in handling cargo, or both. The mooring ports are placed at intervals of about 34 meters along the quay wall.

Figure 6. Phoenecian quay at Atlit showing interlocked and offset slabs where the breakwater joins the quay wall.

Figure 7. Stone quay in river port of Aquileia, Italy (circa 180 B.C.). Quay had landing stages at two levels (for varying river levels?). Note protruding mooring stones shown in Figure 8.

Figure 8. Details of mooring port shown in Figure 7. Port is constructed of three cut stones, morticed together with metal straps.

Julius Caesar, who was proconsular of the Roman Senate, actually became in effect a dictator. Members of the senate, filled with foreboding, killed Julius Caesar on the Ides of March in 44 BC. Civil war followed, until Octavian finally defeated the Egyptians under Mark Anthony at Actium on 31 BC. Following the civil war, Octavian, Julius Caesar's heir, consolidated the country into the first Roman Empire and assumed the title Augustus, reigning from 27 BC to 14 AD. Under Augustus the Roman Empire attained its maximum size, and the only further expansion was the conquest of Britain during the rein of Emperor Claudius (41 AD 54 AD).

The Romans became a great sea power under Agrippa, who was Octavian's (later called Augustus) lieutenant. Also, about this time the Romans attained the summit of their technological skill as harbor engineers. Agrippa constructed the harbor of Miseno near Naples in 31 BC, and it became the main base of the Roman fleet. In 79 AD, Pliny the Elder, who was then commander of the Roman fleet, sailed from Miseno in a futile attempt tc save the people of Herculaneum and Pompeii, and lost his life by suffication from the fumes of Versuvius.

The main breakwater at Miseno is constructed of a double row of Roman arches, joined and capped at the top to form a single solid wall (Fig 9). The arches are staggered so that each support column of the inner row stands opposite an arch of the outer row. This construction technique, borrowed from the very successful use of the Roman arch for aquaducts and bridges, had a number of advantages when employed as a breakwater. The arch concept enabled breakwaters to be constructed in deep water with a minimum amount of stone. The open-but-staggered columns permitted currents to flow freely through the structure, while protecting the harbor from wave action. This novel construction was highly successful at Miseno, where siltaticn was not a problem. The submerged remnants of the support columns for the staggered arches are still in place and the outer row is available for inspection by divers. However, a mcdern rubble mound breakwater has been placed over the inner row of arches.

Staggered, double rows of underwater arches became a favored method of breakwater construction by the Romans, and although not always successful, they were used extensively. For example, Caludius' Port at Ostia near Rome was constructed of staggered arches in 54 AD, as was Sabratha in Africa about 200 AD.

Caesarea was an outstanding example of Roman influence on harbor engineering. The harbor was built on the site of a previous Phoenician harbor by Harod the Great, and was completed in 10 BC (Figure 10). It is described by Josephus Flavius (Antiq. XV 9.6) who wrote, "the harbor is free always from the waves of the sea". It was constructed by reinforcing two reefs, which stretched seaward, with vast stone blocks. A quay encircled the whole harbor, and on the quay were arches "where the mariners dwelt". The underwater ruins of the harbor were studied in 1960 by a group headed by Edwin Link. The main breakwater is in the shape cf an arc that extends 450 meters seaward from the shore, then curves to the north for 370 meters along the shore. The entrance is between the main breakwater

Figure 9. Roman arches supporting the aquaduct leading to Ceaserea, constructed about 20 B.C.. Staggered double rows of underwater arches were a favored method of breakwater construction by the Romans.

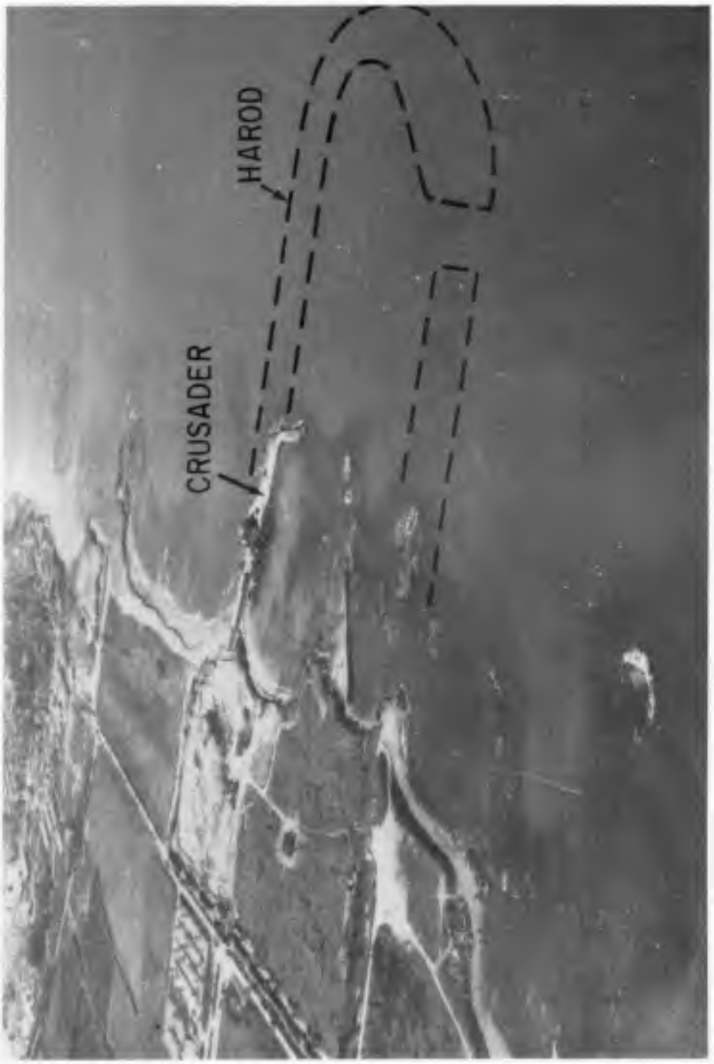

Figure 10. Reconstructed city of Ceaserea and the crusader breakwater and harbor looking south. Dashed line outlines the large harbor constructed by Herod the Great in 10 B.C.

and the north breakwater and is open to the north, which is the direction of the least waves. The average width of the breakwater is 50 meters and the depth is over 7 meters. The size of stone is surprising. The largest stones are 2 1/2 x 3 x 15 meters, and each one weighs about 30 tons (Linder, 1971). Some stones were joined by lead and wood caulking, and others were sealed by molton lead poured in the spaces between the stones. In water deeper than 7 meters, the Romans built up a layered platform of smaller stones for the large stones to rest upon. In water 6 meters or less, they rested the hugh pillars directly on the bottom. Caesarea fell to the Moslems in 638 AD and its sea power faded. It was partially revised under the Crusaders, when it was taken by Baldwin I in 1101. The Crusaders rebuilt and walled about one-tenth of the Roman City, and rebuilt about one-eighth of the harbor (Figure 10). The city was further strengthened by Richard I (1191). It again fell to the Moslems and was demolished in 1265. Stones from its ruins were transported to Akko and Jaffa for building purposes.

Ostia, the port of Rome built near the Tiber, is said to have been one of the finest examples of Roman harbor engineering. The harbor construction was begun by Claudius in 42 AD, and completed by Nero in 54 AD. The principle of the staggered Roman arch was used for the main breakwaters. Although the harbor was magnificently constructed and huge, with an area of 850,000 square meters, it proved not to be safe from waves and was subject to siltation. A storm in 62 AD caused the loss of many ships, and the harbor was eventually abandoned in preference of the hexagonal shaped basin that was built in 98 - 117 AD by Trajan. The ruins of Claudius' harbor are landlocked and have not been excavated. The ruins of Trajan's harbor are landlocked and easily visible from the air (Schmiedt, 1964).

Harbor design became progressively more stereotyped during the last half of the Roman era, and their construction was characterized by massive structures that required large armies of workmen. Innovative concepts in design, and attempts to work with natural elements, appear to be absent. As a result there were a greater number of failures. The Roman empire gradually declined and experienced a series of serious invasions by the Huns beginning in 406 AD. The Huns under Atillia invaded again in 433-55 AD. In 455 AD, the vandal king, Gaiseric, built a fleet that began the domination of the Mediterranean from the west, and caused the Roman empire to be restricted to the eastern Mediterranean. There was a brief resurgence of the Roman Empire in 600 AD, but by 626 AD, Egypt and the western Mediterranean fell to Islam, and a Byzantine empire replaced the Roman in the central and eastern Mediterranean.

CRITIQUE

Most of the world's population has always lived near the coast where the seas are the means of transportation and a source of food. This close association with nature gave the Minoans and Phoenicians a very superior "lay" understanding of waves and currents which is evident in their coastal engineering works. Since they lacked the technology for harnessing large amounts of power, they developed remarkable concepts in working with natural forces, as can be seen by an inspection of the ruins of their ancient harbors.

These natural approaches and the resulting "gentle architecture" carried through to Roman times. The Romans developed staggered, double rows of underwater arches as a favored method of breakwater construction. The staggered arches provided baffles for dissipating waves, while permitting currents to flush the harbor. However, harbor design became markedly stereotyped following the development of large engineering corps with the capacity for rapid and massive construction. The earlier innovative, natural concepts in harbor design appear to have become obscured by the end of the Roman era, and have remained relatively unused to this day.

Harbor technology had brief resurgences during the Crusader times, when Genoese and Venetians constructed some remarkable harbors including that at Heraklion, Crete. Following this,there was a general decline in technology until the beginning of the age of world exploration in the 15th century AD. However, it now appears that we have again passed through a zenith in harbor technology and are now in what would be equivalent to a "second Roman decline". This is attested to by the numerous "white elephants" that line our coasts. In view of man's present extensive intervention in the coastal zone, mostly based on "brute force" technology, a careful study of the ancients' ability to work with nature provides valuable insight for today's problems.

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