Historical Environmental Changes at Phalasarna Harbor, West Crete*

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The ongoing archaeological excavations that started in 1986 on the site of the harbor of Phalasarna have confirmed that the ancient port described as a closed harbor by ancient geographers is, due to the regional uplift of west Crete, now situated on dry land, about 6.6 m above sea level. In this paper, after summarizing the geological background, the main historical sources and recent archaeological results, new stratigraphical data obtained from the sediments filling the harbor basin are presented and discussed. The harbor was fortified in the second part of the 4th century B.C. It was a military port, probably a base for pirates, and was destroyed and abandoned in the second part of the first century B.C. After that time the harbor basin was rapidly silted by marine then terrestrial sedimentation. Deposits corresponding to two tsunami waves have been identified and ascribed to events occurring in 66 A.D. and 365 A.D., respectively. About 1530 ± 40 yr B.P., probably in 365 A.D., when west Crete was suddenly uplifted by 6–9 m, Phalasarna harbor was removed permanently from marine influence. Radiometric dating confirms that the harbor could not have been in use in Roman times, in contradiction with ancient *Periploi*, which continue to mention Phalasarna port until at least the second or third century A.D.

INTRODUCTION

Until very recently, the ruins of Phalasarna (35°30′N–23°34′E) [Figure 1(a)] were usually considered to be Roman, owing to ancient texts suggesting that

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the harbor was active until at least the second or third century A.D. It was, however, difficult to accept that an artificial harbor could suddenly have been abandoned in historical times without any historical account of this being found, especially since it has been demonstrated that the uplift of west Crete corresponds to an event which occurred 1530 ± 40 yr B.P. (Thommeret et al., 1981; Pirazzoli et al., 1981, 1982).

The archaeological excavations carried out by the Department of Antiquities of west Crete in 1986 and 1987 have revised these ideas, demonstrating (Hadjidaki, 1988a,b) that the fortifications of Phalasarna, built in the second part of the 4th century B.C., had in fact been destroyed, that the harbor entrance was blocked and the site abandoned as early as the second part of the first century B.C.

The present study shows that after its entrance was blocked, the basin harbor rapidly silted up; when the uplift event took place, the harbor was completely filled with sediments and its existence and former use probably forgotten even by the Cretan inhabitants.

GEOLOGICAL BACKGROUND

Situated in the middle part of the Hellenic arc, near the southern limit of the Ionian Trench, where crustal subduction is still active (Le Pichon and Angelier, 1979; Angelier et al., 1982), the island of Crete has been affected by important tectonic movements during the last several million years. These movements were usually the result of normal faulting, due to the extension of the Aegean crust, combined episodically with rapid crustal rebound events related to subduction processes.

The sequence of vertical movements which have taken place in the west part of Crete over the last few thousand years are known in detail, owing to a series of emerged, superimposed shorelines which have been identified and dated (Thommeret et al., 1981; Pirazzoli et al., 1981, 1982). This sequence consists of a series of small, probably sudden subsidence movements of the land (which caused an apparent rise by steps of relative sea level), followed by a strong uplift movement (which caused a sudden apparent fall of the sea relative to the land). The most impressive movement is also the most recent one; dated consistently by nine samples belonging to the uppermost raised shoreline, it took place about 1530 ± 40 yr B.P. This movement consisted of an almost rigid uplift, probably of coseismic origin, accompanied by northward tilting, affecting a huge lithospheric block about 200 km long, including western Crete and Antikythira Island. Although large faults between western Crete and Antikythira have been reported in various papers by geophysicists, seismological surveys, and oceanographic profiles, these do not seem to have been reactivated during the last 4000 years. The largest vertical displacement (about 9 m) has been measured near the southwest corner of Crete; at the Phalasarna site the displacement was 6.6 m. Such a movement is among the largest coseismic

Table I. Relative sea-level changes at Phalasarna during historical times, deduced from radiocarbon-dated sea-level data published by Thommeret et al. (1981) and Pirazzoli et al. (1981, 1982)

Shoreline	Elevation (m above present MSL)	Displacement Age		
		yr B.P.	Calibrated Age[a] Range	Inferred Historical Age
0	±0			
		1530 ± 40	341–439 A.D.	365 A.D. (21 July)
I	+6.6 ± 0.1			
		1600–1710	89–404 A.D.	
II	+6.5 ± 0.1			
		1780–1800	16 B.C.–169 A.D.	66? A.D.
III	+6.35 ± 0.1			
		1880–1900	141 B.C.–69 A.D.	
III_A	+6.25 ± 0.1			
		1950–1980	235–18 B.C.	
IV	+6.1 ± 0.1			
		2250–2300	728–378 B.C.	
IV′	+5.9 ± 0.1			
		2500–2610	991–759 B.C.	

[a] Calibration according to Stuiver et al. (1986), using a one σ standard deviation and $\Delta R = -80 \pm 25$ yr for the Mediterranean area, according to Stiros et al. (1992).

displacements observed in the world and is unprecedented in the Mediterranean, at least as concerns Holocene uplifts.

This conspicuous crustal movement was not confined to Crete and Antikythira, but was accompanied by a number of crustal adjustments all around the eastern Mediterranean, some of which have already been dated in Lebanon and Turkey (Pirazzoli et al., 1991). These movements, which correspond to a period of very high seismic activity in the eastern Mediterranean area, reported between the 4th and the 6th century A.D. in several ancient texts, probably correspond to a phase of adjustment between the different crustal plates which are in contact with each other in this area; this has been called the Early Byzantine tectonic paroxysm (EBTP), owing to the time it occurred and the extent of the geographical area involved (Pirazzoli, 1986).

In western Crete and Antikythira, the uplift of about 1530 yr B.P. was preceded by three millennia during which a series of ten rapid subsidences (from 10 to 25 cm each time) affected part of the same lithosphere block, without any noticeable tilting (Pirazzoli et al., 1982).

The above crustal movements are now sufficiently well established and dated to enable the construction of a graph of relative mean sea level (MSL) changes during the last few thousand years at most sites of western Crete, e.g., in Phalasarna since 1000 B.C. [Table I, Figure 1(b)]. The relative sea-level band of Figure 1(b) has been constructed by using dated samples collected from the outer surface of fossil rims consisting of *Dendropoma petraeum* and/or of *Neogoniolithon notarisii*, which develop at the sea surface (Laborel, 1986, 1987;

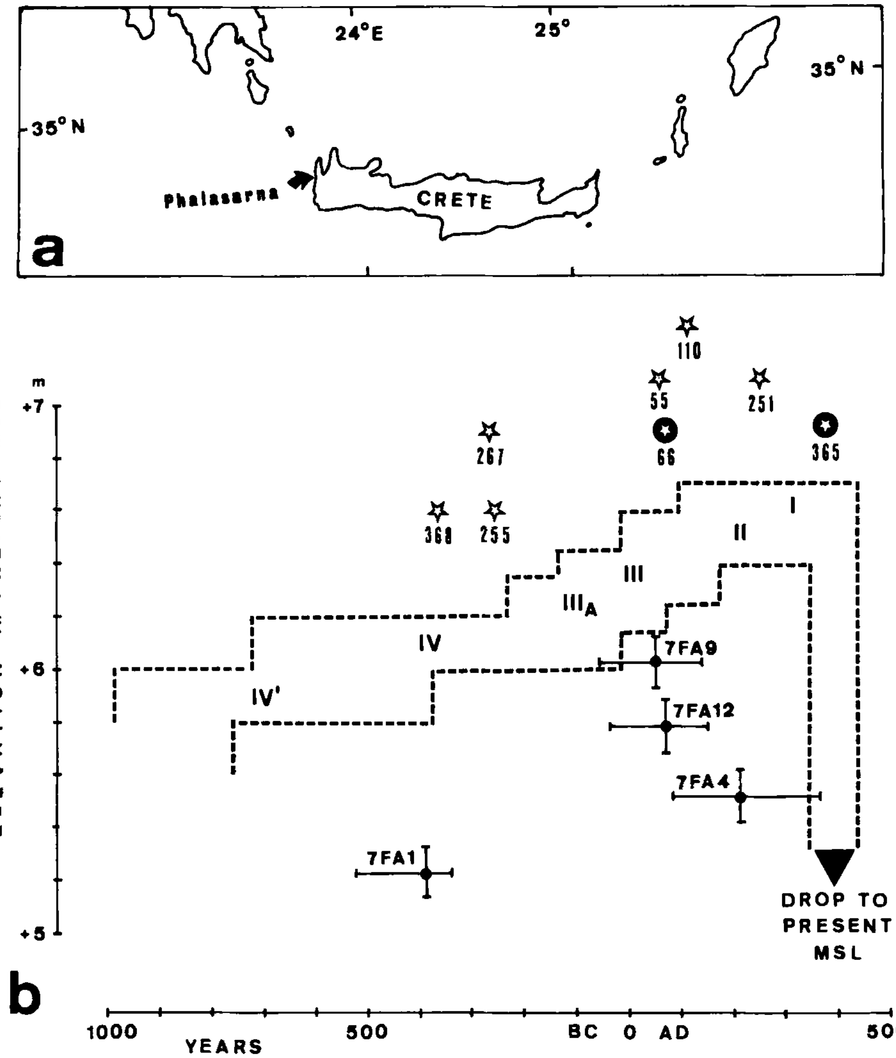


Figure 1. (a) Location of Phalasarna harbor. (b) Band of relative sea-level changes at Phalasarna between 1000 B.C. and A.D. 500, compared with historically destructive earthquakes (open stars) and tsunamis (encircled stars) in Crete. The radiocarbon dates plotted in the graph refer to four samples mentioned in the text.

Kelletat and Zimmermann, 1991); the sea-level band takes into account uncertainty ranges in elevation and age deduced from data published by Thommeret et al. (1981) and Pirazzoli et al. (1981, 1982) and the discussion on calibration ages by Stiros et al. (1992). Roman numerals correspond to the naming of superimposed shorelines already used in previous papers. The actual relative

MSL has changed by steps (as shown by the morphology of constructional and erosional marine features) inside the band. The cause of these changes was probably coseismic vertical movements of the land. Historical destructive earthquakes and tsunami waves reported in Ancient Crete are also plotted in Figure 1(b).

HISTORICAL SOURCES

Ancient literature mentions the existence of the harbor of Phalasarna several times. The earliest reference, ascribed to the 4th century B.C., is probably that of Scylax, who mentions "*Phalasarna cum portu clauso*" (Phalasarna with a closed harbor) in his "Periplus of the Inner Sea" (47).

Strabo, who is believed to have interrupted the writing of his *Geography* about 2 A.D., and resumed his work some 15 years later in order to mention more recent events (Baladié, 1978), cites Phalasarna twice (X, 4, 2; X, 4, 13).

The references to "*Phalasarna. . .clausum quae habeat portum*" (. . . which has a closed harbor) by Dionysius Calliphontis (118–122) (Müller, 1965), which probably dates from the second century A.D., and the one to Phalasarna by Ptolemy (2nd century A.D.) in his *Geography*, suggest that the harbor was still functioning at that time.

Lastly the *Stadiasmus* (336) mentions, among other ports, Phalasarna ("*ibi statio est, emporium, urbs antiqua*") (here there is a stopping place, a supply market, an ancient town). It is uncertain when the *Stadiasmus* was written; some authors ascribe it to the beginning of our era; Rougé (1966) and Pédech (1976) date it from the 2nd or 3rd century A.D.; other authors from the mid-3rd or the 4th century A.D. Pendlebury (1939) finally ascribes it to Byzantine times, between the 6th and the 11th century, adding (24) that it must be the 6th century "for it mentions Phalasarna, which went out of use in the middle of the 6th century," but the sources of this astonishing information are not given. These historical texts explain why, until the beginning of the archaeological excavations in 1986, the ruins of Phalasarna were usually referred to as Roman, although the city was known to have been founded in earlier times.

THE PHALASARNA SITE

Phalasarna was a small port on the west coast of Crete (Figure 2). The 100-m high rock cape upon which the acropolis was built, today called Kutri, had a strategic location as it dominated certain sea routes between Alexandria, Greece, and Italy. Present evidence shows occupation of the site from the Late Archaic to the late Hellenistic periods (Tzedakis, 1969; Hadjidaki, 1988b).

Among the public buildings surviving today, some of considerable height, and others in the form of toppled walls overgrown with brush, one can discern temples, various cisterns, and wells (Pashley, 1837; Savignoni, 1901; Hadjidaki, 1988a,b). The lower part of the hill is lined by a 550 m long stretch of double

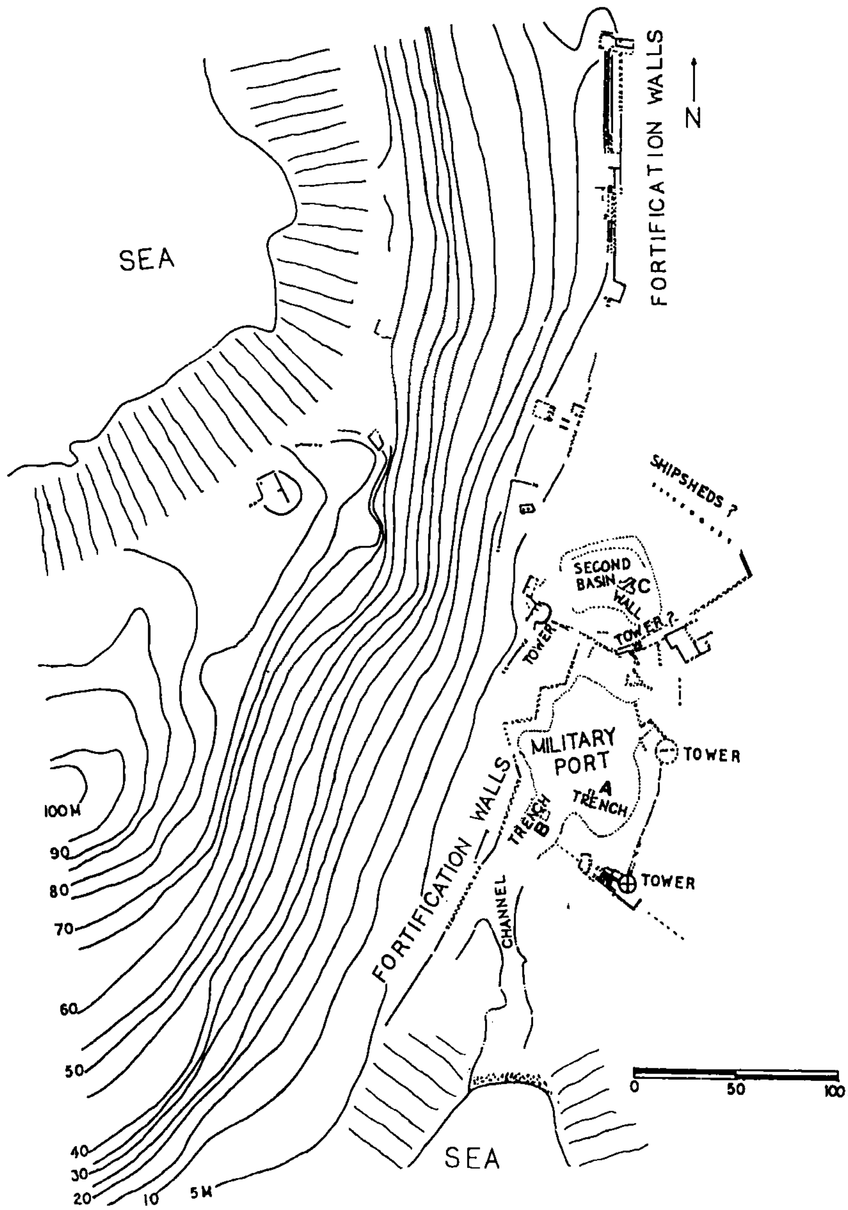


Figure 2. Plan of Phalasarna harbor. Location of trenches A, B and C are shown.

fortification walls, with three defensive bastions *in situ*, all built of sandstone in an isodomic style. Extensions of these main defensive walls towards the east and southeast enclosed the artificial harbor of the town. Southeast of the fortifications, along the rocky coast, are the sandstone quarries which supplied the town with building materials. Among the quarries there is a curious structure hewn into the rock, measuring ca. 5 × 5 × 3.5 m with two flights of stairs leading inside it. This basin has been interpreted as a salt pan (Savignoni, 1901), a funeral chamber (Cayeux, 1907), a tank for the storage of water or other goods (Flemming et al., 1973), or an unfinished fish tank (Flemming and Pirazzoli, 1981; Pirazzoli, 1988). Its purpose, however, remains uncertain, for its top must have been close to sea level in ancient times.

The location of the ancient harbor was identified by Spratt (1865) and confirmed by Savignoni (1901), Lehmann-Hartleben (1923), Flemming et al., (1973), and Hadjidaki (1988a,b). At the foot of the acropolis is a flat round space measuring roughly 100 × 75 m, which now lies about 7 m above the present sea level, surrounded on all sides by extensions of the city's fortifications or high rocks. A 120-m-long dry channel connects the area to the sea. This channel is today overgrown with bushes and filled with artificially cut stones. A secondary shallow channel, diverging from it, may have served for desilting. Both of these channels may originally have been natural fissures, but they bear clear evidence of having been widened artificially, thus making the first channel a navigable passage from the harbor to the sea. Excavations around the area since 1986 have proven that this region was the closed harbor mentioned by ancient geographers and that the harbor basin had been subsequently completely filled by sediments and uplifted.

During recent archaeological excavation, a small trench (A) (Figure 4) was cut in the middle of the flat area. It uncovered marine deposits, most often *in situ,* mixed with ca. 4th century B.C. pottery, coins, nails, and bronze arrow heads. The depth of the trench was 1.8–1.9 m from the present soil level to the limestone bedrock forming the harbor basin floor, the elevation of which is here ca. 5.0 m above present MSL.

A second trench (B) (Figure 7) was cut at the mouth of the channel, just before it enters the harbor. The sediments from within contained abundant eroded Hellenistic pottery, *Ostrea* shells, gravel, and sand. Excavation stopped at 1.7 m below the present soil level, which is here at about + 7.4 m, not because the floor of the channel had been reached, but because huge worked sandstone blocks prevented any further digging (Figure 7). The size of these blocks, which were found only in one part of the channel, suggests that they came from a sea wall, and the way they were scattered in the channel suggests a deliberate act of war to prevent the port being used, rather than the effects of a natural hazard, like an earthquake or a tsunami. This leads to the hypothesis that the channel was purposely blocked, probably by the Romans in 67 B.C. during their campaign to suppress piracy.

Massive fortifications can still be seen surrounding the area at all points

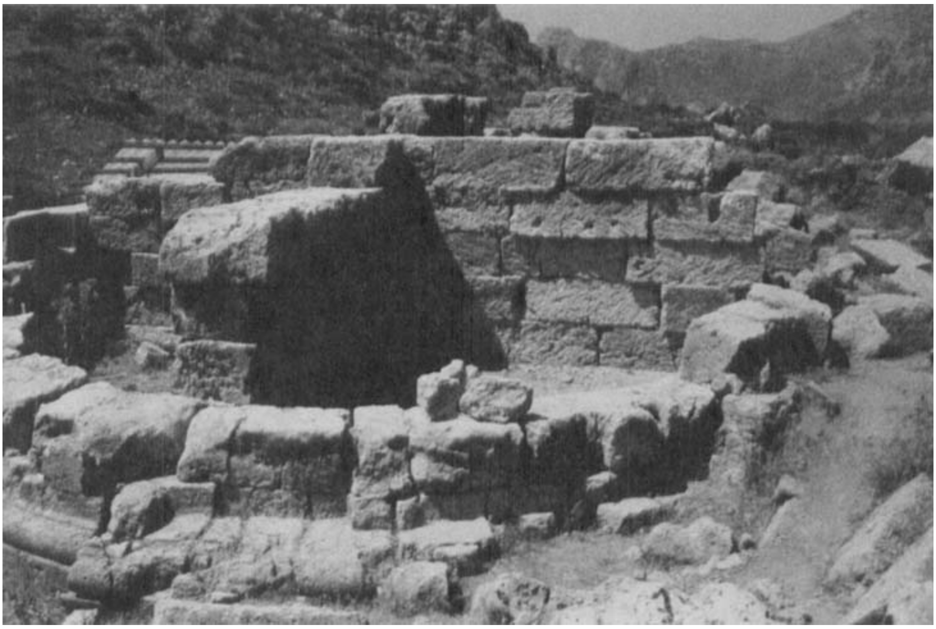


Figure 3. South harbor tower (photo by P.A. Pirazzoli).

apart from the channel entrance. Two of the four high mounds along the course of fortifications have been excavated so far. Both of them have yielded remains of defensive towers. The southern tower is round, 4.5 m high, and is divided internally into 4 quarters by two crosswalls (Figure 3). The external surface of the tower is carefully finished, and near its bottom there is an elaborate rounded molding. Adjoined to the tower is an apsidal water tank measuring 3.75 × 2.75 m. Its walls have been plastered with two coats of hydraulic cement and finished with a final coat of black paint. The south tower must have guarded the entrance to the sea, and the ancient cistern may have supplied water to the ships as well as to the guards of the tower.

Two long walls on the exterior western flank of the tower run parallel to each other at a distance of some 2.9 m. The outer one seems to have been a protective sea wall that enclosed the tower. The moat between the two walls is now filled with a loose conglomerate consisting of Hellenistic sea-worn sherds, sand, and pebbles, capping a layer of green silt. These deposits seem to have been brought in by some natural catastrophe, such as a tsunami (Hadjidaki, 1988b).

The northern tower is 200 m away from the sea and has a rectangular shape. It is not yet completely excavated, but 5 m of its height probably survive. Its walls are also isodomic, but the faces of the stones are pulvinated rather than smooth. A rectangular opening at the lower end of what has been uncovered leads to the suggestion that this was a gate between the harbor and the city.

The walls that leave this structure on either side are part of the series which encircle the harbor, leading towards the north to a large semi-circular tower which is part of the city fortifications. Thus the harbor is a "closed" one, as described by Scylax.

A second flat area, measuring 50 × 35 m, lies to the north of the main harbor at about 7.5 m above present sea level. It had been supposed that this region served as a secondary port. However, this working assumption has been challenged by a series of facts. A break in the walls surrounding the area could not be found. In its center, a trench (C) uncovered a beautiful isodomic wall; 8 m in length have been excavated but the total length is probably at least 30 m; and the wall seems to continue towards a perpendicular line of 10 stones in a row, spaced evenly at 4 m. Excavation reveals the east of the wall was dry land, whereas to the west the levels slope down steeply at an angle of 20° and seem to have been under freshwater.

Suggestions have been made that the line of parallel stones belongs to the remains of shipsheds. A geophysical survey has found a series of buried parallel walls departing from these stones. Their purpose at the head of a narrow freshwater basin which was probably unconnected to the sea (see below) is, however, unclear.

THE INFILLING OF THE HARBOR BASIN

Trench A

The sediments infilling the harbor basin are commonly sands or silts, enriched with shells and occasional pebbles. At two levels, however (just above +5.9 m and +6.4 m), more or less rounded blocks of different sizes are disposed along two almost horizontal layers (Figures 4 and 6).

A preliminary analysis of sediments from the floor of the trench revealed deposits of *Ostrea* shells, echinoid detritus, microfauna, and miscellaneous grains. Subsequently, 15 samples were collected from a vertical profile at regular intervals between +5.2 and +6.6 m and analyzed.

Lithology and Macrofauna

Most of the deposits consist of muddy carbonate sands. Carbonate material corresponds most frequently to rounded bioclastic particles or, in the upper part of the profile, to debris of pedogenetic calcareous crusts. Between ca. +5.7 and +5.9 m, at the base of the first layer with irregular blocks, a sharp decrease in carbonate material occurs, accompanied by an increase in siliciclastics (Figure 5).

Between +5.2 and +5.5 m, sand and small gravel consist mainly of shell debris, often rubefied, with frequent recognizable remains of Lamellibranchi-

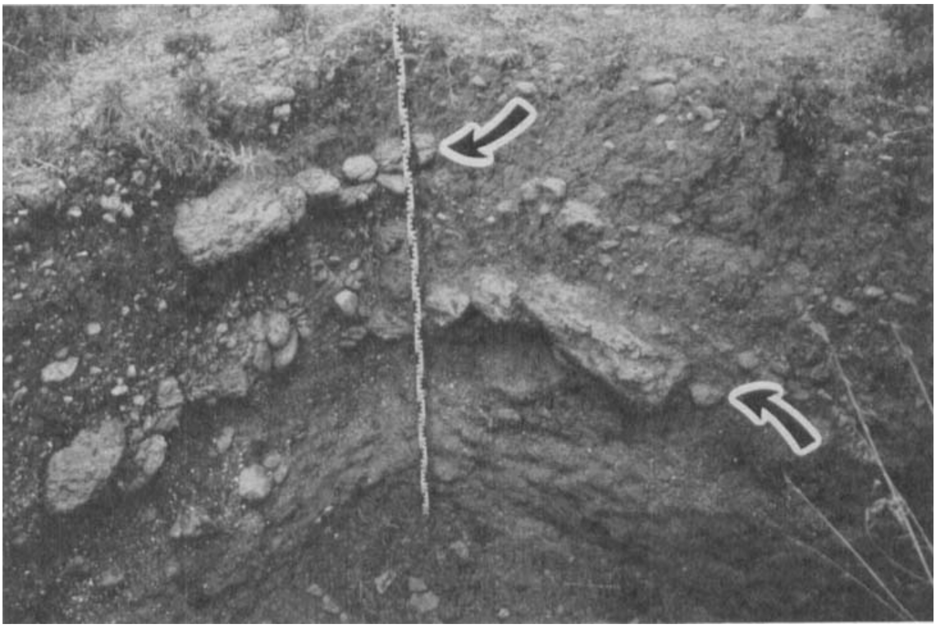


Figure 4. Trench A, in the middle of the military port basin. Arrows indicate two horizontal layers of coarser material with blocks, interpreted as tsunami deposits (photo by P. A. Pirazzoli).

ata, gastropods (*Littorina*), Madreporaria, serpulids, and echinoids; rubefied debris of sandstone (1–10 mm in size) are frequent while quartz is rare.

At ca. +5.6 m sandstone debris disappear and small *Hydrobia acuta* gastropods are very frequent. *H. acuta* lives in algal environments between sea level and a depth of 20 m and is especially resistant to freshening.

Between +5.7 and +5.9 m, marine sand and gravel are often replaced by a terrestrial red pedogenetic gravel, though several small algal-bed gastropods are still present.

Between +6.0 and +6.15 m, mollusc and gastropod shells are abundant, though *H. acuta* is very rare.

Above +6.5 m there are many gravels of various rocks and carbonate crusts; small-sized sediments are missing and marine traces are rare.

Microfauna

Benthic Foraminifera can be found in the sediments filling the ancient harbor basin between the basin floor and +5.8 m, then again near +6.0 m. On the other hand, Foraminifera are absent near the +5.9 m level and above +6.15 m. The following 30 species have been identified: *Ammonia beccarii, A. parkinsoniana, A. tepida, Amphistegina sp., Asterigerinata mamilla, Amphi-*

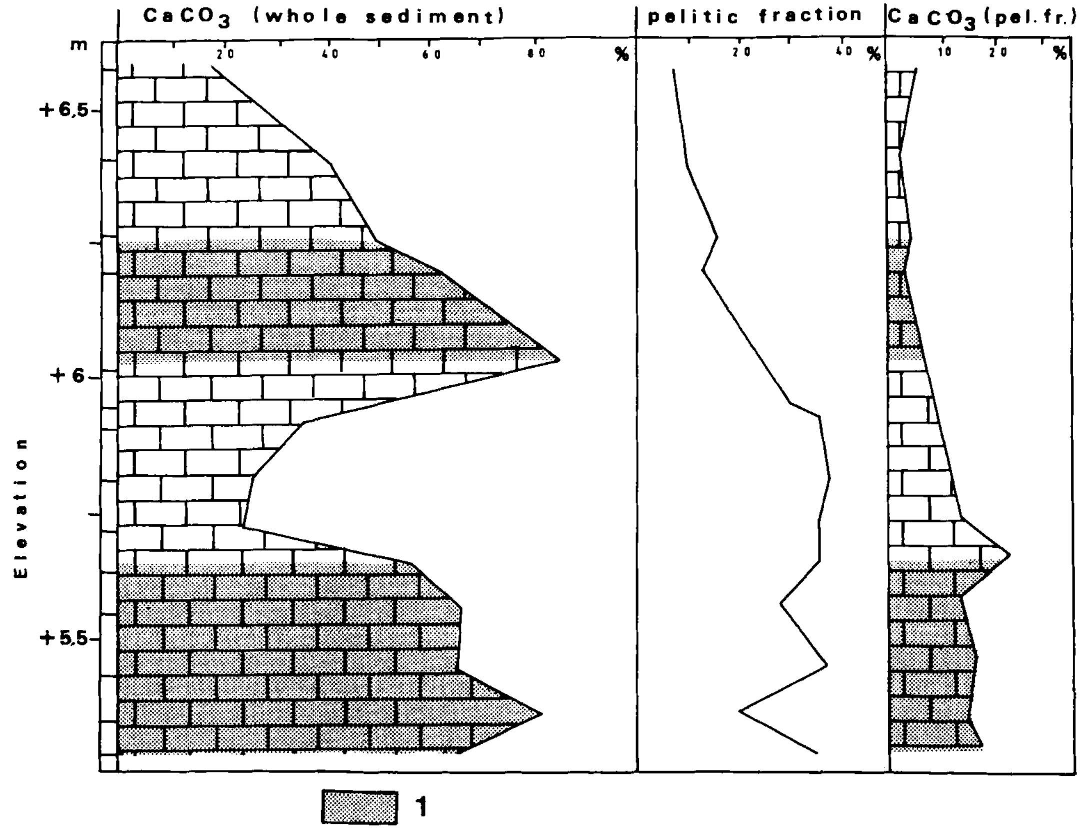


Figure 5. Carbonate and pelitic contents of the whole sediment and carbonate content of the pelitic fraction (pelitic fraction is designated as <40 μm) along a vertical profile in Trench A. The carbonate fraction results from the association of marine biogenic particles and pedogenetic remains; in each case (whole sediment or pelitic fraction), it decreases above +6 m with the decline of marine intrusion; concurrently, the pelitic fraction is replaced by the sandy quartzos fraction. Note a recurrence of marine influences towards +6 m. 1: dominant marine biogenic particles.

stegina sp., Biloculinella sp., Cassidulina sp., Cibicides advenus, C. lobatulus, C. refulgens, Elphidium aculeatum, E. advenum, E. crispum, E. macellum, Eponides repanda, Globigerina bulloïdes, Globigerinoïdes ruber, Massilina secans, Nonion commune, Peneroplis pertusus, P. planatus, Quinqueloculina aspera, Q. berthelotiana, Q. bicornis, Q. rhodiensis, Q. viennensis, Q. vulgaris, Rosalina globularis, Spiroloculina ornata, Triloculina laevigata, T. oblonga, and *Valvulineria bradyana.*

Most of the Foraminiferal shells are worn, rubefied, sometimes broken; only the smaller tests (*Ammonia*) are well preserved. The density of individuals of each species is rarely high; the best represented families are those of *Miliolidae* (which have strong shells), *Rotaliidae, Cibicididae,* and *Peneroplidae,* which are specific to warm waters (Glaçon, 1962).

The microfauna habitat seems to have been between 5 and 15 m deep, probably on a sea grass bed, which is very favorable to the development of *Miliolidae* and *Peneroplidae* (e.g., *Posidonia* or *Cymodocea* beds in the Mediterranean) (Blanc-Vernet, 1969; Venec-Peyre and Le Calvez, 1981; Venec-Peyre, 1984).

Foraminifera correspond to an algal-bed population at the lowest levels of the profile studied, whereas, between +5.3 and +5.8 m, the specific variety and the number of individuals decrease upwards, suggesting a habitat more confined and sheltered, and occasionally freshened (presence of *Ammonia tepida*).

Near +5.9 m the biotope is extremely confined, and only Ostracoda, less affected by freshening, are still present. At +6.0 m microfauna becomes more varied again, typical of an algal bed, indicating a renewed marine influence, which decreases sharply however above +6.15 m; here any permanent connection with the sea seems to have been interrupted and only episodic storm waves were still able to deposit a little shell debris in the basin.

The stratigraphy of trench A has been summarized in Figure 6.

Trench B

The stratigraphy of this trench has been summarized by Hadjidaki (1988b). Above the sandstone blocks scattered randomly at all levels, a fairly horizontal layer with medium-sized blocks, similar to the layers at +5.9 m and +6.4 m in Trench A, is visible at +6.7 m (Figure 7).

Trench C

The lowest level contains freshwater shells. Four samples of sediments were collected along a vertical profile and analysed. At about +5.3 m and +5.75 m, some worn shell debris exists, suggesting an episodic marine influence only at the time of heavy storms. At higher levels (e.g., at +6.2 m and at +6.7 m) marine deposits are totally absent.

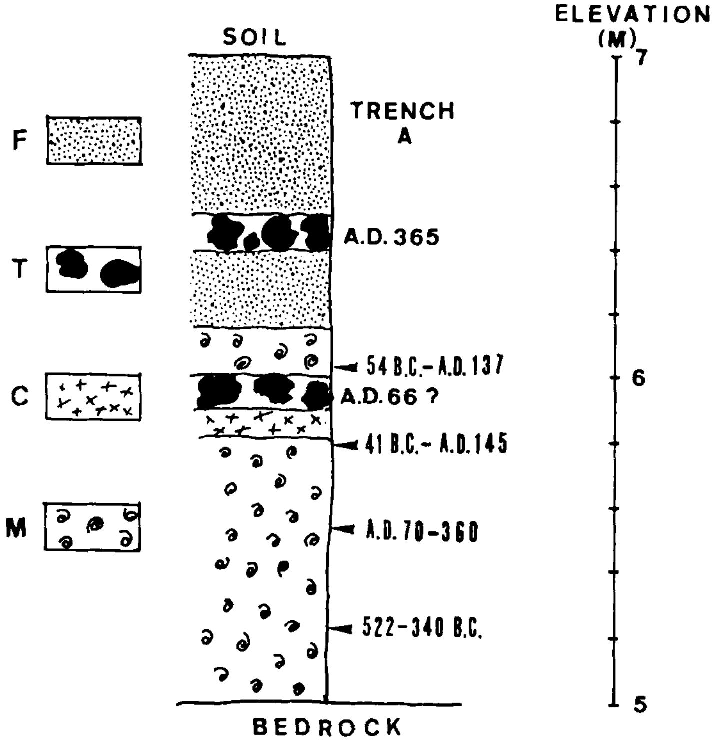


Figure 6. Simplified stratigraphy of trench A. F: freshwater (terrestrial) deposits; T: tsunami deposits; C: confined marine deposits; M: marine deposits. Arrows with dates correspond to the positions of four samples for which new radiocarbon dates were obtained from the present survey (see Table II).

RADIOMETRIC DATING

The main points to be clarified were the contradiction between the absence of Roman occupation suggested by preliminary archaeological excavations and the presence of Phalasarna among harbors listed in Roman times as active, and possible correlations between changes in the harbor environment and the tectonic movements (especially tsunami waves) which affected the area.

Four samples were chosen for radiocarbon dating: near the upper limit of marine sediments, just above the lower layer with blocks of different sizes (7FA9); just below the preceding layer with blocks (7FA12), in order to constraint its age estimation; and at intermediate levels between this layer and the bedrock, to assess the period during which the harbor could have been active and the velocity of infilling in the harbor basin.

Three samples to be dated consisted of *Hydrobia acuta* shells, collected at ca. 23, 52, and 103 cm above the basin floor, and a fourth sample consisting of two

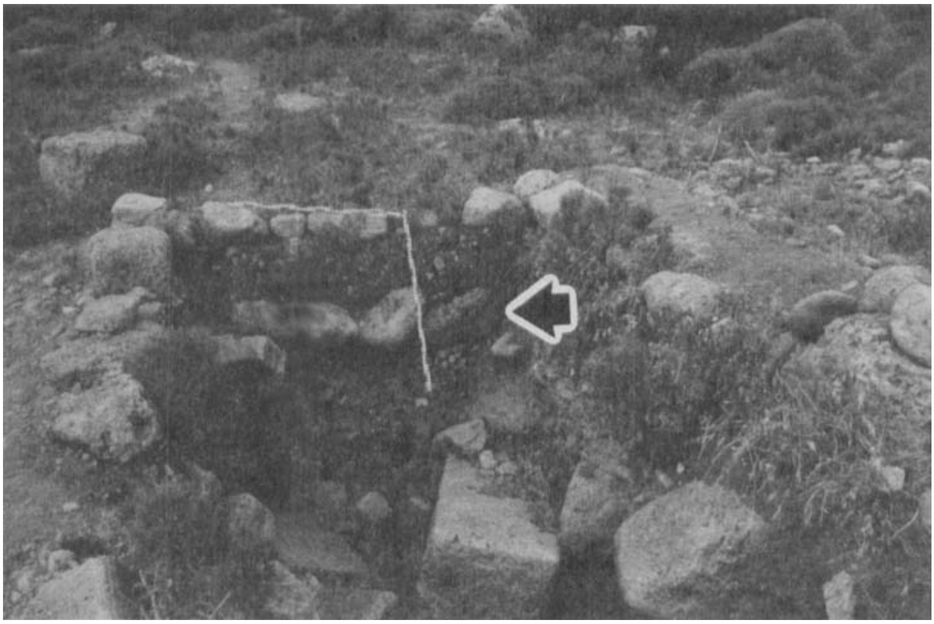


Figure 7. Trench B, looking seawards. Arrow indicates a layer of coarser material with blocks, which is interpreted as corresponding to the upper layer of tsunami deposits in Trench A. In the foreground, some huge worked sandstone blocks, which prevented deeper excavation, are visible (photo by P. A. Pirazzoli).

joined shells of *Cerastoderma glaucum*, collected in living position c. 79 cm above the basin floor. Due to the small quantity of material available from these samples (less than 10 mg of carbonate for the smallest), the accelerator mass spectrometry (AMS) technique has been used with the Tandetron facility at Gif-sur-Yvette, where ^{14}C measurements of samples containing 0.5–2 mg of carbon are routinely performed (Arnold et al., 1987; Arnold et al., 1989).

Conversions of the radiocarbon ages into calibrated dates have been obtained using the calibration curve of marine samples by Stuiver et al. (1986). A ΔR value equal to -80 ± 25, calculated from the apparent age of three shells of known age collected in the western Mediterranean (Stiros et al., 1992), has been used with the calibration curve.

The results obtained are summarized in Table II. The most reliable date is probably that provided by the *Cerastoderma* shell, whereas the *Hydrobia* samples, each consisting of several shells, may have been affected by partial mechanical reworking or freshening contamination and are therefore to be considered as indicative only. The dates of samples 7FA1 and 7FA9 seem fully reliable, however (the apparent age of 7FA4 is discussed below).

Table II. List of dated samples from sediments filling the Phalasarna harbor basin.

Sample No.	Altitude (m above MSL)	Material	^{14}C age (yr BP ± σ)	Calibrated Date[a]
7FA1	5.23 ± 0.1	*Hydrobia acuta* shells	2200 ± 90	522–340 B.C.
7FA4	5.52 ± 0.1	*Hydrobia acuta* shells	1680 ± 120	70–360 A.D.
7FA12	5.79 ± 0.1	*Cerastoderma glaucum* shell	1810 ± 80	41 B.C.–145 A.D.
7FA9	6.03 ± 0.1	*Hydrobia acuta* shells	1820 ± 80	54 B.C.–137 A.D.

[a] Calibration according to Stuiver et al. (1986), using a one σ standard deviation and $\Delta R = -80 \pm 25$ yr.

DISCUSSION

The most unexpected result provided by archaeological excavations has been the absence of any evidence of occupation of the harbor of Phalasarna during Roman Imperial times, in contradiction with several ancient texts. The stratigraphical and paleoecological data provided here confirm that the harbor was not in use during Roman times. The area was inhabited since at least Minoan times and a town already existed at the Phalasarna site in the 6th century B.C. The southwest tower of the harbor dates to the second half of the 4th century B.C. (Hadjidaki, 1988a,b). At that time or a few decades later, as suggested by coins and by an inscription (Hadjidaki, 1988a,b), Phalasarna was an independent town minting its own coins and already a naval power; there is little doubt that the excavated harbor was a military port, probably one of the famous Cretan pirate nests terrorizing the Mediterranean.

Sometime in the first century B.C., the town and the military defences of the harbor were destroyed, and the narrow harbor mouth was deliberately blocked to prevent the port being used. This may have happened in 67 B.C., when, according to Plutarch (*Pomp.*, 29.1), Caecilius Metellus was sent as praetor to Crete and destroyed a number of pirates' strongholds, subjecting all the island to Rome and gaining the appellation *Creticus*. Although Phalasarna is not mentioned by ancient writers in accounts of this campaign, there are good reasons for believing it was involved, owing to its strategic location and because the remains of various impressive public buildings and fortifications prove the existence of financial and human resources that only piracy could have provided in such a place. Frost (1989) suggests even that the destruction of Phalasarna may have occurred at the very start of Metellus' campaign, before the Roman landing at Kydonia, in order not to leave a hostile, fortified port only a day's sail to his rear; this would have been consistent with the Roman military practice to make an example of an isolated case at the beginning of a campaign and discourage future resistance.

The sherds produced by the archaeological excavation suggest that the site was abandoned near the end of the first century B.C.; evidence of a resettlement in Roman times has been discovered only at one place located about 4 km south of Phalasarna harbor.

Knowledge of relative sea-level changes and tectonic movements is essential in order to understand the stratigraphic sequence of sediments filling the ancient Phalasarna harbor basin and the environmental changes which occurred after the harbor was built.

The water depth in the harbor suddenly deepened by 1 or 2 dm on at least four occasions between the time of its construction and ca. 1530 yr B.P., when the basin was definitely raised seismotectonically and removed from any further marine influence.

In the second half of the 4th century B.C., when the southern defence tower was built, sea level can be estimated at about +6.1 ± 0.1 m, corresponding to shoreline IV [Figure 1(b)]. This corresponds to a water depth of about 1.1 ± 0.1 m at the point of trench A, possibly deepening northeastwards, if the 3° slope of the bedrock observed on the floor of trench A remains constant. These depths were sufficient for a harbor, given the displacement of 4th century B.C. pirate ships, which were smaller and lighter than the standard trireme.

In 67 B.C., when sea level was between +6.1 ± 0.1 m and +6.35 ± 0.1 m, the harbor basin was slightly silted, at least at the location of trench A (see sample 7FA1, Table II), where water depth was between 80 and 125 cm [Figure 1(b)]. At the time of the earthquake-tsunami event reported in Crete in 66 A.D. (Galanopoulos, 1961; Di Vita, 1986), the relative MSL may have jumped from +6.25 ± 0.1 m (shoreline III_A) to +6.35 ± 0.1 m (shoreline III), or, more likely, from +6.35 ± 0.1 (shoreline III) to +6.5 ± 0.1 m (shoreline II). Subsequently, the sea level rose further to +6.6 ± 0.1 m in one or two more small, sudden movements, as shown by the uppermost small tidal notches cut into the outer limestone face of the secondary harbor channel.

On the site of Phalasarna harbor, however, no obvious Roman remains have been discovered so far. After the harbor entrance had been blocked, probably in 67 B.C., the harbor basin was rapidly filled by marine sediments, as indicated by the *Cerastoderma glaucum* shells collected at 80 cm above the basin floor, dated with 0.67 probability between 41 B.C. and 145 A.D. Sample 7FA4 gave a slightly younger apparent age, but if a 2σ standard deviation is used, its calibrated age range (80 B.C.–490 A.D.) would be consistent with the stratigraphy. Slightly above this level, a first layer with irregular blocks occurs, suggesting a tsunami wave event, which must also have washed emerged land around the harbor, bringing into the basin much of the siliciclastic material observed in the harbor stratigraphy between +5.7 and +5.9 m. Some 20 cm higher in the same section, just above the tsunami deposits, a sample of *Hydrobia acuta* gave an age between 54 B.C. and 137 A.D., which is statistically indiscernible from the *Cerastoderma* date. The tsunami wave, which deposited a layer with several blocks at ca. +5.9 m in Trench A, probably corresponds to the 66 A.D. event; at that time sea level was only a few decimeters above the sediments in the basin.

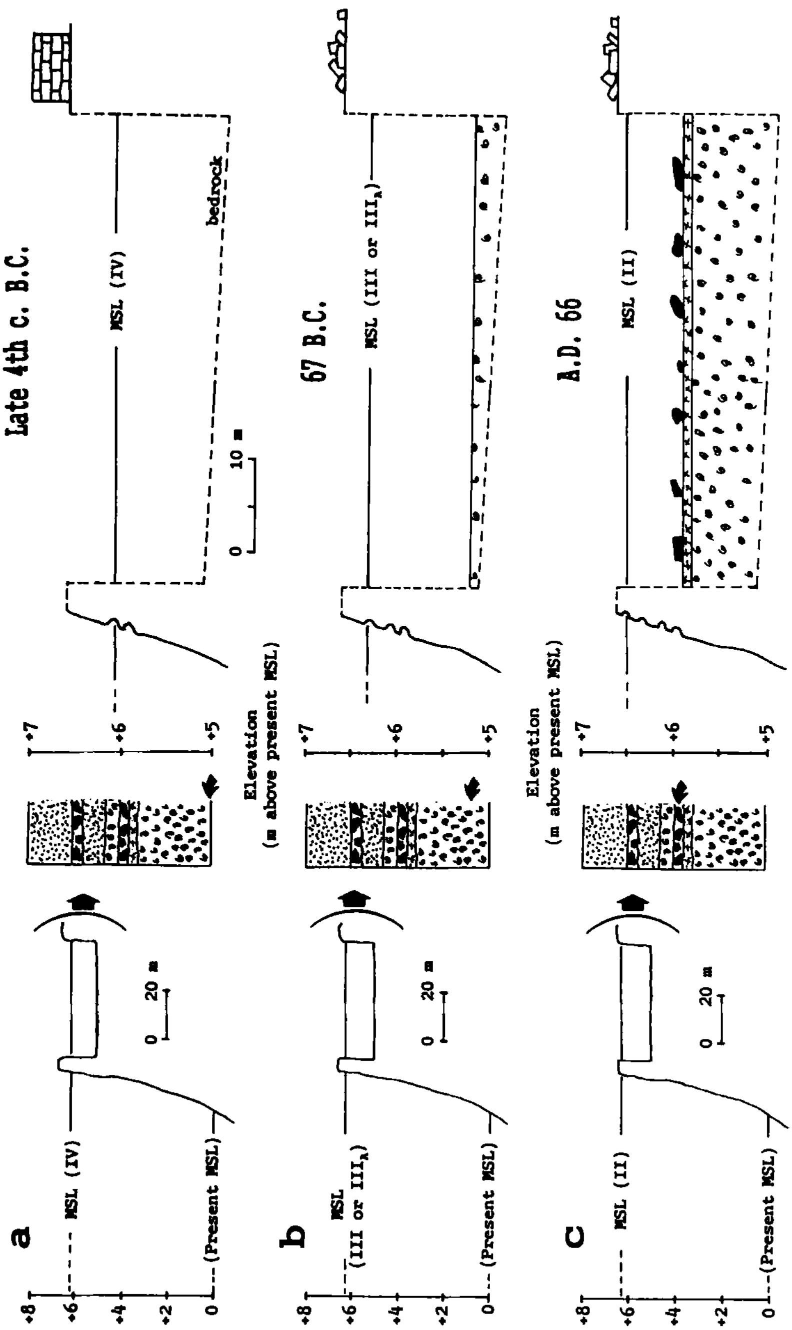
The increased marine influence shown in the deposits between +6.0 and +6.15 m can easily be explained as a consequence of an increased influx of seawater across the area of the blocked channel, due to a sudden slight subsidence movement which occurred between 16 B.C. and 169 A.D., displacing the shoreline from III to II (Table I). Of the three great earthquakes reported from Crete during this period (in A.D. 55 A.D., 66 A.D., and 110 A.D., respectively, according to Galanopoulos, 1961), the 66 A.D. event was followed by a tsunami wave.

The basin entrance seems to have been completely closed shortly afterward, interrupting any stable connection with the sea. After that time, marine traces were brought only by occasional storm waves.

The Phalasarna port cannot therefore have been active at the times of Dionysius Calliphontis, Ptolemy, and probably even Strabo. This would confirm a fact, already noted by some historians, that most ancient *Periploi* seem to have borrowed much information from earlier *Periploi,* without rigorous systematic checking; sometimes they mention ports which were no longer used (such as Phalasarna, in this case), whereas other ports, just constructed, were disregarded. The main sources of Strabo for Crete, for instance, would have been Artemidor and Apollodorus, neither of whom, however, had ever been to the island (Lasserre, 1971). The fact that the harbor of Phalasarna is mentioned until at least the 2nd century A.D. may mean that another closed harbor basin, not yet found, existed near Phalasarna, or, more likely, that ancient compilers did not update earlier data or consult correct information sources. Later versions of the *Periploi* which report on the existence of the Phalasarna port in the second or third century A.D. may have been merely copies from earlier more accurate *Periploi* by Greek geographers. These writings must therefore be considered critically, and it is hazardous to consider them absolutely reliable.

An exceptional seismotectonic event, which occurred on 21 July 365 A.D., has been reported in many ancient writings, 30 of which have been analyzed by Jacques and Bousquet (1984). According to the vertical displacements produced in Crete and Antikythira, the epicentre of the main shock is likely to have been located between the southwestern tip of Crete and the Hellenic Trench, rather than off the central part of southern Crete (Jacques and Bousquet, 1984) or off northern Crete (Guidoboni et al., 1989). Destructive tsunami waves generated by this earthquake are known to have affected a wide range of Mediterranean areas, from the eastern coasts of Sicily to the Ionian Islands, Epidaurus in the Adriatic (Guidoboni et al., 1989), the southern Peloponnesus, the southern coasts of Crete, and the Nile Delta area (Alexandria). Important destructions have been dated from the same period also in Leptis Magna, Oea, and Sabrata (Tripolitania) (Di Vita, 1990).

This tsunami probably left the upper layer of blocks in the stratigraphy of the basin sediments, at +6.4 m in trench A and at +6.7 m in trench B, whereas the area of trench C does not seem to have been affected by this event. The effects of the 365 A.D. tsunami wave, which was probably much stronger than in the case of the 66 A.D. event, were relatively limited in the Phalasarna sediment stratigraphy. This can be easily explained if the same seismotectonic


a
b
c
Late 4th c. B.C.
67 B.C.
A.D. 66
MSL (IV)
MSL (III or III$_A$)
MSL (II)
(Present MSL)
bedrock
Elevation (m)
Elevation (m above present MSL)
0 20 m
0 10 m

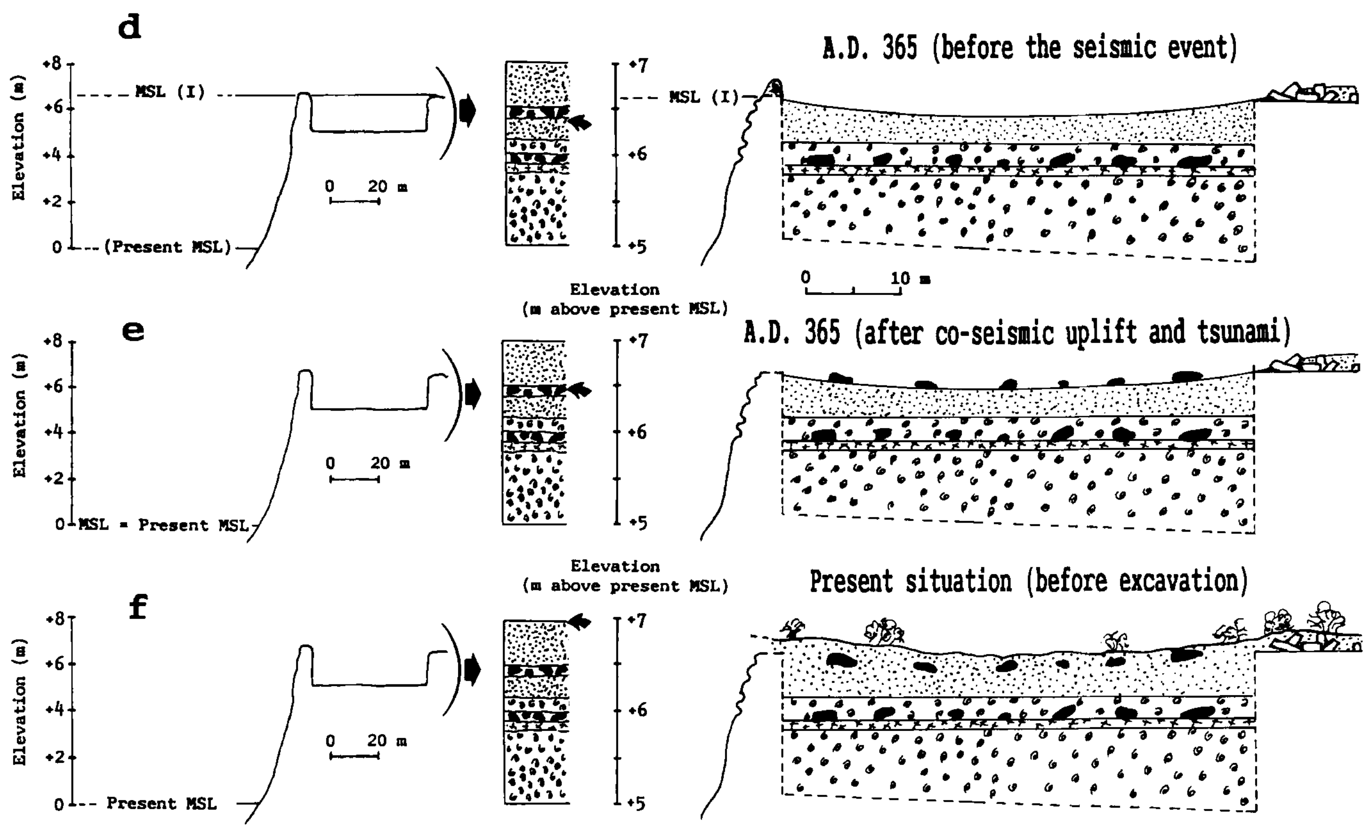


Figure 8. Model to explain the stratigraphy in the Phalasarna harbor basin. Marine sedimentation began immediately after the closure of the entrance channel by the Romans in 67 B.C. and continued until the second half of the first century A.D., when sea level was reached by the sediments in spite of some subsidence movements. The upper sediments have a terrestrial origin. Large rocks were deposited by two tsunami waves, possibly in A.D. 66 and 365. The 6.6-m uplift movement which raised the site may also have occurred in A.D. 365.

movement which caused the tsunami wave in 365 A.D. had also uplifted western Crete. If this was the case, the Phalasarna site was already uplifted 6.6 m, if only a few minutes before the wave arrived. According to the calibration curves by Stuiver et al. (1986), 1530 ± 40 yr B.P. corresponds to the calendar range 341–439 A.D. with a probability of 0.67 (1σ) and to 265–491 A.D. with a probability of 0.95 (2σ). These ranges are more consistent with the date 365 A.D. than previous calibrated ages deduced by Thommeret et al. (1981) from earlier conversion tables, which are less accurate for marine samples. It seems likely, therefore, that the 365 A.D. event corresponds to the tremendous uplift movement which raised the Phalasarna area about 6.6 m.

A model to explain the stratigraphy of the harbor basin at Phalasarna is outlined in Figure 8.

CONCLUSION

Converging archaeological, stratigraphic, geomorphological, and radiometric evidence has enabled the environmental changes which occurred at Phalasarna during historical times to be clarified. After the town and its harbor were destroyed and abandoned, probably in 67 B.C., rapid silting took place in the harbor basin. In spite of a sequence of small seismo-tectonic subsidence movements, one of which, accompanied by a tsunami wave, may have occurred in 66 A.D., the upper part of the infilling consists of terrigenous sediments, indicating that the basin was isolated from the sea. In 365 A.D. the site was finally uplifted 6.6 m in a sudden movement and washed by a new tsunami wave.

Ancient texts mentioning the Phalasarna rock-cut harbor in Roman times are in contradiction with the absence of any evidence of Roman occupation and with the age of the sediments filling the harbor basin. This contradiction may be explained either by the existence of another Phalasarna closed harbor basin, the location of which has not yet been discovered, or, more likely if the topographical situation of Phalasarna is considered, by the fact that some ancient writings may have been based on a compilation of earlier obsolete sources of information.

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