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Survey of Building Techniques at the Roman Harbours of Carthage and Some Other North African Ports

The study of harbours presents the marine archaeologist with the problem of submerged stratigraphy. Only in exceptional circumstances will the site be other than in shallow water, often murky with pollutants stirred up by surface water activity, with extensive overbuilding by successive installations and confused by physical destruction by waves and erosion. This also increases the difficulty of the physical process of excavation.

Under these conditions, the likelihood is reduced of finding the evidence of wooden construction materials now so relatively abundant in deepwater shipwreck archaeology.

The description in this paper of the discovery of intact wooden materials used at or below water level is the result of archaeological surveys carried out by the authors at a number of ancient harbour sites on the coast of the Maghreb, culminating in several seasons at Carthage. The work at Carthage included three short seasons of underwater excavation associated with the British contribution to the UNESCO Save Carthage Project, under the direction of Dr. Henry Hurst and sponsored by the Save Carthage Committee of the British Academy.

The data presented here represent only a part of the full findings which will form the full report now in preparation on this excavation and survey work.

HARBOUR TECHNOLOGY

The ancient sources on technical harbour construction are few. From the little that has come down to us and from the physical evidence available to us, we can identify about five different construction technologies.

The inland dry harbour is one of the earliest attested to; the reference from Virgil[1] to the construction of that at Carthage called Cothon is particularly apt in the context of this paper. The one recently excavated in Egypt[2] is a fine example. It is certain though that from the earliest times natural physical features would have been embellished with simple structures in wood or stone, to which we have little reference. Evidence such as the fresco depicting wooden jetties at the site of Puteoli and the recent excavations of the Roman waterfront at Londinium are indicators that this was a well developed technique by Roman times.

The use of boulder banks or breakwaters must have started at an early date, but did not reach its full scale until the development of transportation technology enabled large volumes of material to be readily moved by land or sea and dumped in great banks in the water. The description by the younger Pliny[3] of the construction of Centumcellae is evocative of the process by which an estimated ten thousand cubic metres of quarried stone was used in the construction of the 1 km long Roman harbour mole found by the authors at Thapsus in Tunisia.

The elegant use by ancient Greek engineers of ashlar masonry walls at considerable depths must have involved great technological expertise. We do not know that this sort of sophistication was matched by the Romans until the development by the Augustan engineers of hydraulic mortar which would set underwater. This then allowed them to cast structures in wet conditions, either adhering directly to existing natural rock features, as at Sabratha for instance, or as free standing masses of which the arched mole at Puteoli is probably the most celebrated example. In this technology the use of wood was crucial. Vitruvius[4] describes in detail, in one of the most important ancient references, just how this casting process was carried out.

Ashlar construction techniques are seen underwater in Hellenistic North Africa, at Apollonia and Tolmeita, but most remarkable in the brutally monumental Severan harbour at Leptis Magna. The harbours at Carthage recently excavated by Hurst[5] and by Stager also show fine examples of Punic and Roman masonry construction in these land locked basins, but it is the technology of cast concrete that draws our attention time and time again along the North African coast.

ROMAN CONCRETE

Three basic methods were used for creating the form to which the concrete would be cast, each generally requiring the use of wood. Firstly, there were the situations where formwork was constructed around natural features such as reefs. This was particularly popular where offshore dunary reefs existed as in the example of Sabratha cited above, but was also used in situations such as at Thapsus, where the physical feature might have been artifically constructed. We can surmise that the erection of this could only have taken place in relatively shallow water owing to the natural buoyancy of the wood and the difficulty of doing the necessary carpentry underwater.

To achieve any depth, some measure of prefabrication would be necessary. This could have amounted to sets of panels which could be weighted, sunk and then joined and clamped in place. Alternatively, complete box sections could have been lowered into the water. The concrete would then either be cast with the box flooded or partially emptied using pumps. Casting loads on the shuttering would be initially inward for the pumped out method, but outward as the wet mortar rubble mixture was poured in.

Finally, the casting form could be completely fabricated on dry land and floated into place and sunk. This might most conveniently be effected by pouring the mortar and rubble mixture into the floating box which would then sink progressively. Hydrostatic loads would thereby remain somewhat balanced. Dubois in his "Observations sur un passage de Vitruve"[6], describes how such a structure if cast on a bank of sand might have been submerged by a process of erosion. Such a process would be either beneficial or not, depending on the situation. In sandy or unstable locations where an accurately located block was required, it would have been necessary to create a sufficiently extensive and reinforced structure to minimise any possible subsidence. As the concrete or mortar rubble mixture was poured in, very large outward pressures would be generated as the level rose above the surrounding water, requiring the sort of reinforcement of which Vitruvius speaks.

THE EVIDENCE

The excavations at Carthage have enabled us to see some of these techniques in use at first hand. The results are, as always, tantalisingly fragmentary. Future analysis will depend on many other factors, such as ancient sea levels being established beyond doubt from the land excavations.

The situation and history of the circular military and rectangular civil harbours of Carthage need little introduction. (Fig. 1) Hurst and Stager who have been responsible for the very successful excavations in the circular and rectangular harbours respectively, provide an excellently concise review in their article "A Metropolitan Landscape: The Late Punic Port of Carthage"[7]. Their final reports now in preparation, have been preceded by regular interim reports with a wealth of valuable data.

The land excavations have not yet concentrated on what now remains the most enigmatic area of the ancient harbours — the entrance and the "Choma", referred to by Appian[8] in the area beyond the reputed entrance. It is in this region that the attention of the authors has focussed with assistance in the early surveys that must be credited to J.H. Little and a team from Cambridge University, led by the late Keith Muckelroy.

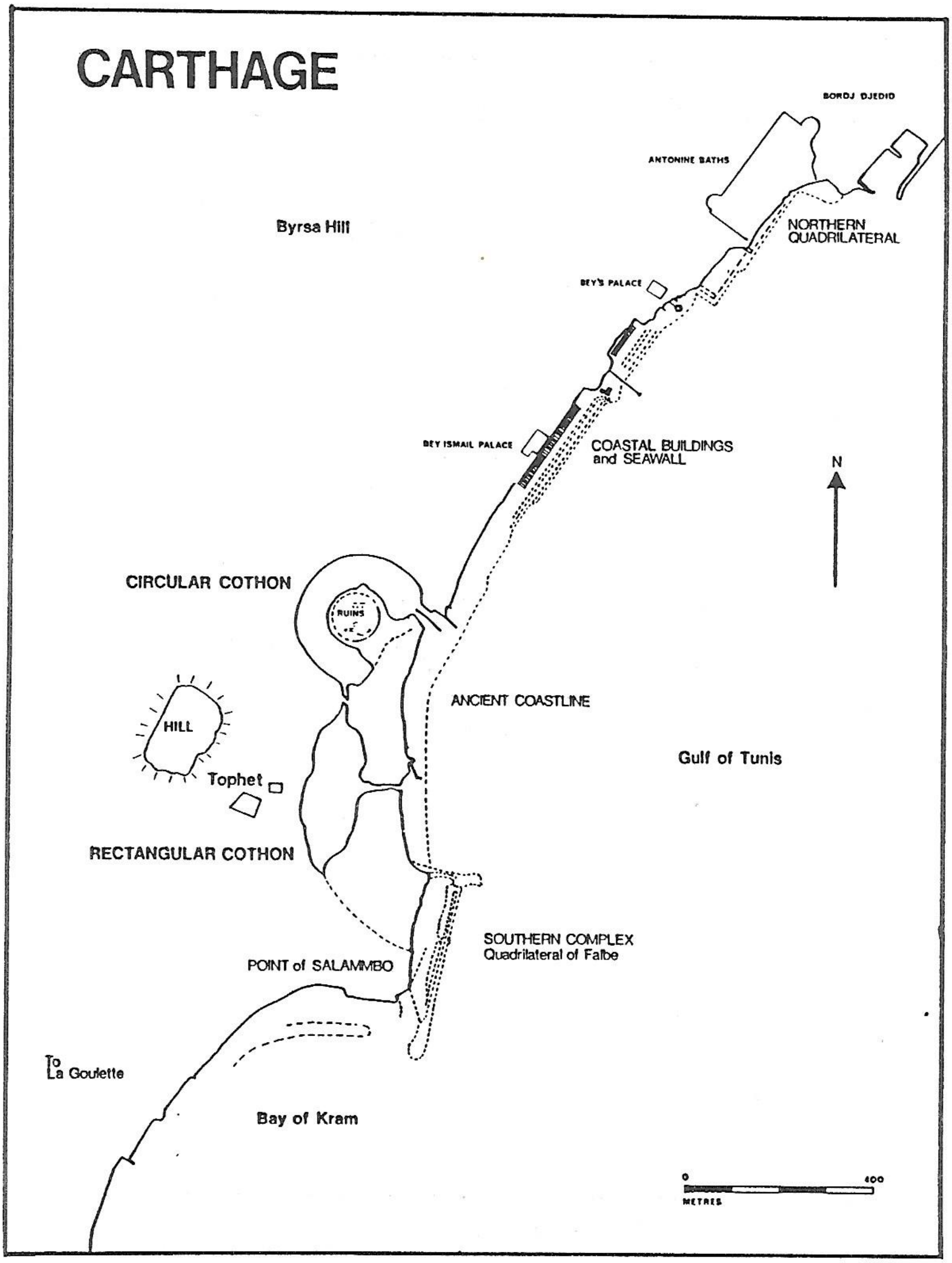

Figure 1. Carthage: The coastline.

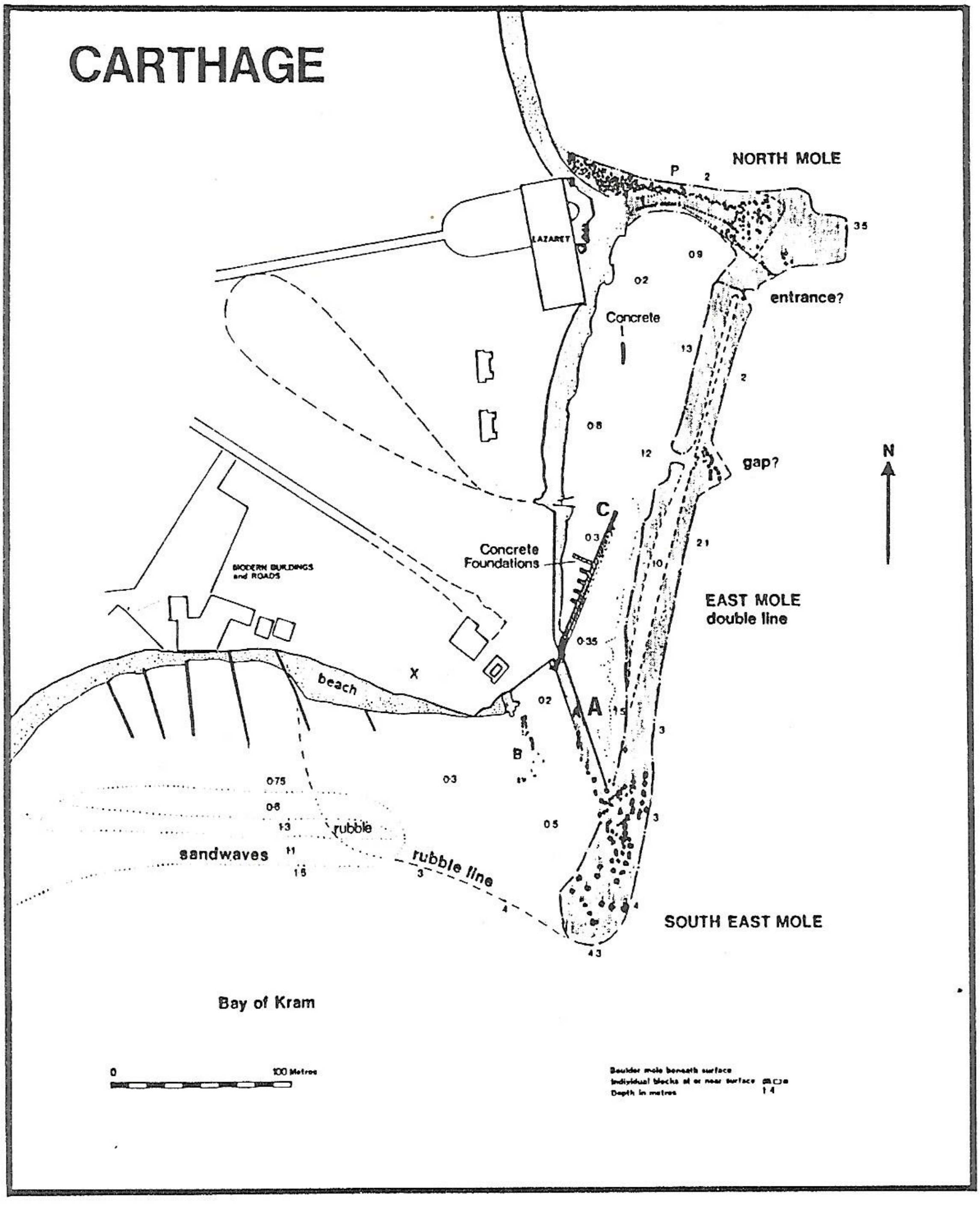

Figure 2. Carthage: Southern complex (quadrilateral of Falbe).

In the area known as the Quadrilateral of Falbe (Fig. 2) there were known to be a number of structures of uncertain date and purpose. These have all now been accurately surveyed and in the course of the limited exploratory excavation that was carried out to delimit their extent, some fascinating wooden details were revealed.

SHUTTERING ON WALL A

The excavation carried out at the northern end of Wall A, in 20 cms of water depth, revealed that beneath the silt and shingle were the well preserved remains of a wooden lattice framework against which the wall had been constructed. In contrast to conventional shuttering for the casting of concrete, the framework was formed of three sets of orthogonal timbers. The first set comprised vertical posts (10 cm by 15 cm in cross section) set at least 1 m apart as support posts. Horizontal beams (6 cm by 12 cm), were then nailed to the face of these posts, allowing vertical laths (5 cm by 10 cm) to be attached as required. As these laths were spaced at 5 cm intervals, the wall cannot have been constructed by casting and it can be presumed that the facing stones would have been built up against the face of the laths with a mortar rubble fill as the core of the wall. This seems to indicate that the shuttering had been constructed to prevent debris from tumbling into the construction trench which had been cleared in the ground.

It is clear that no attempt had been made to produce any elaborate jointing of the timber, which had simply been nailed together. The horizontal beams were discovered at a depth of 60 cm below current sea level, which would have made the hammering of nails an extremely irritating if not unacceptable operation. It is tempting, therefore, to propose that there has been a sea level change of at least this magnitude. This supposition, however, runs contrary to other evidence found by Hurst that sea level has not changed by that amount. We must, therefore, assume that this area was part of the land at the time of construction.

Two further examples of wooden shuttering were found while excavating Wall C. Wall C comprises a linear mortar rubble structure some 110 m long running north-eastwards into the centre of the Quadrilateral from a point in the south-western corner. Against the west or shoreward edge can be seen a number of abutting walls.

Beyond the fifth of the cross walls the seabed is eroded and the wall is not found but reappears after 20 m in two continuous but separate sections, the second of which has settled and turned at an angle of 7 degrees to the north.

Considerable efforts were made to determine whether this wall had ever continued further into the Quadrilateral. Several trenches were cleared both on the projection of the line and in the spaces between adjacent structures. In none of these areas was there any indication of a continuation. Finally, a short distance beyond the extreme end of the last visible section, the remains of wooden shuttering were found in position below the seabed, defining the end of the wall. This shuttering proved to be very different from that which was also found in situ around the cross walls further south, although all other indications were that the sections were part of the same structure.

ABUTTED WOODEN SHUTTERING OF WALL C

In the corner between one of the cross walls and Wall C was found a section of vertical wooden shuttering planks. A small excavation was undertaken to expose the face down to its full extent where it was bedded on a layer of stones. The wood, identified as a species of Fir, survived to within 30 cm of the seabed and was extremely well preserved. The planks were 30 cm wide, 2-3 cm thick and 1.65 m long and had been roughly tapered with an axe at the bottom end to ease penetration into the ground. The points were so little damaged, however, that it was clear that they had not been driven forcefully through rough ground. Their vertical edges were simply abutted and at a depth of 1.10 m horizontal beams one of Fir, one of Pine, half jointed at the corner, retained them in place.

It is assumed that the erection of this shuttering took place in an open, wet trench which had been cleared down to a stone layer. The planks would then have been driven in individually and held in place with the horizontal timber.

The extremity of the most northerly of the cross walls was also investigated and a shallow trench revealed remains and imprints of very similar shuttering, continuing all around the faces. It was not possible to continue this excavation although it was clear that at least four of the cross walls are not continuous compartment walls, but more probably buttresses or supports for the main foundation.

JOINTED WOODEN SHUTTERING ON WALL C

Further wooden shuttering was found just beneath the seabed surface in fine clean sand, retaining the most northerly outcrop of mortar rubble on the line of the wall. At this point the water depth was 1.90 m where there can be little reasonable doubt that one is dealing with a fully submerged contruction process. The shuttering was followed down an outside face for some 50 cm before excavation became impracticable. There was no indication of a base or of any external horizontal bracing timbers.

The timbers were very different from those found in the abutted shuttering in that, although they were also set vertically, the edge faces had been grooved centrally on both edges and engaged one with another, to provide a substantially sealed tongue and groove joint (with an offset of one third of the plank thickness). A vertical rectangular post 10 cm x 7 cm was found adjacent to one corner outside the shuttering and would have been part of the bracing needed to support the structure during construction. The thickness of the planks varied from 4 to 5.5 cm. The widths of the planks appeared to have been close to a standard 43 cm, but obviously with variations in those adjacent to the corners. The edges of the planks in the end face had been tenonned to leave a central tongue 2.5 cm wide, which engaged with a continuous mortise slot on the inside of the side face planks.

Such a configuration could have been assembled in sections, but as it would have required considerable precision to have engaged the continuous mortise and tenon, it is more likely that it is the remains of a prefabricated box.

HORIZONTAL SHUTTERING ON CAUSEWAY PIER

On the northern side of the island, in the circular harbour, are the remains of a number of piers from a causeway or bridge structure, that formerly connected it to the land. One of these was excavated in the black waters of the almost stagnant lagoon.

It proved to comprise three elements of two principal periods. The central Punic section was built in opus quadratum style with blocks up to 1.35 m x 1.15 m, forming a substantial structure 2.5 m wide across the axis of the causeway and 3.4 m in the axial North-South direction. This central buttress stood on a stepped base with offsets at 1.7 m and 2.2 m below sea level. On the southern face of the pier, the lower of these two formed a step 75 cm wide. Above it the stone which may formerly have formed a distinct third offset had been damaged by dredging, leaving a rough angled surface.

On either side of this central section were two Roman wings of concrete, or mortar rubble, giving the pier a total cross-axis width of 12.5 m. These two wings had been formed by casting, as remains of the timber shuttering were found against the faces adjacent to the opus quadratum core. In contrast to conventional shuttering which is piled vertically, the Fir planks in this instance had been placed horizontally.

The edges of the planks had been half-lapped and tenonned with loose, hardwood tenons dowelled in place. This wood survived in situ on both sides of the pier, continuing to the level of the top of the blocks, although the imprint in the mortar showed that it had formerly continued a further 10-15 cm higher. Horizontal beams were found 52 cm below the top of the opus quadratum supporting the horizontal planks. The vertical posts that would have been needed to support the structure were not present as the shuttering had been roughly torn away at the corners to allow the gap between the mortar rubble and the opus quadratum to be filled in with small stones and mortar.

On the excavated South faces of the two wings, evidence was found of wooden re-inforcing elements that had been used in the construction of the shuttering as suggested by Vitruvius (see prior reference). The imprints of these were practically symmetrical in each wing, comprising a cylindrical beam set parallel with and above a horizontal plank. If this unexpected combination of geometries served some more specific function, it remains obscure. No further imprints were found on the faces, although search was made difficult by the heavy encrustation of weed and concretion. Such a construction method bears all the hallmarks of waterproof structures. In this case, however, the configuration of the joints would indicate excess outward pressure such as would be seen in a casting done on land.

CROSS BRACING

The circular beams and flat planks noted above in the causeway pier are assumed to have been cross bracing similar to that described by Vitruvius. These would have been necessary to provide the casting box with the necessary rigidity, but may also have provided a measure of reinforcement in large structures.

The element of reinforcement is probably evident in the large platform of concrete that can be seen in the water off the "Neptune Restaurant" on the Carthage waterfront, between the two sets of coastal buildings. This is a vast raft of concrete 18 m x 9 m, which appears to lie at the end of one of the major roads of Roman Carthage. It is very obviously criss-crossed with an orthogonal lattice of holes which were originally wooden beams. Substantial timbers, 25x25 cm braced the two walls of the shuttering. These were stabilised on the horizontal plane, by axial timbers 25 x 14 cm, which were notched to a depth of 10 cm to engage the braces. Vertical posts 13 to 16 cm in diameter provided further reinforcement. Some of these abutted the horizontal beams, in order to support them, others were apparently freestanding.

Such cross bracing is evident at a number of North African sites where concrete masses are seen, such as Cherchell, Tipasa, Hergla and most revealingly at Thapsus. The authors first investigated the site of Thapsus in 1966 and most recently in 1977. Here, the exposed faces of the concrete mole, (which may, incidentally, have been faced with ashlar masonry) are being continually eroded by the sea.

The collapsing structure has revealed a number of apertures in which calcified remains of wood could be seen. It was seen here that all the vertical members of the lattice were engaged with the cross pieces, of which there are a large number.

These horizontal timbers were set about 1.40 m apart and were mostly semi-circular, about 10 cm in diameter.

CONCLUSION

The different examples of wooden shuttering found at Carthage and other North African sites throw a new light on the Roman technology of casting concrete.

In principle, there are similarities to Vitruvius's text (although no double-wall caissons were found), but what is apparent is the many different ways in which the shuttering was constructed and the precision with which a relatively mundane constructional item was fabricated.

Furthermore, it shows how well preserved such items of wood can be, even in very shallow water and gives us the lead to look closer in other harbour areas, where concrete construction is used, for more examples of this technology.

NOTES:

1. Virgil: *Aeniid* I 427.
2. Kemp, B. and O'Connor, D., "An Ancient Nile Harbour", *International Journal of Nautical Archaeology*, Vol. 3, No. 1, March 1974.
3. Pliny: *Letters* VI.31.
4. Vitruvius: *De Architecture* XII.
5. Hurst, H.R., et al Carthage, In publication by The British Academy, 1984.
6. Dubois, "Observations sur un passage de Vitruve", *Melanges de l'Ecole Française a Rome*, 1902, p. 439ff.
7. Hurst, H. and Stager, L.E., "A metropolitan landscape: the late Roman port of Carthage, *World Archaeology*, Vol. 9, No. 3, February 1978
8. Appian: *Roman History* ~~XCVI~~. CXXI = Libyca, 121