Geology, Materials, and the Design of the Roman Harbour of Soli-Pompeiopolis, Turkey: the ROMACONS field campaign of August 2009

To the west of Mersin, on the south-east Mediterranean coast of Turkey, lie the ruins of the port city of Soloi or Soli/Pompeiopolis, now surrounded by the modern town of Mezitli (Fig. 1). The city has a long maritime history. Excavations of the mound beside the Roman-era harbour, directed by Professor Remzi Yagcı of the Dokuz Eyül University, Izmir, have revealed Hittite and Late Bronze Age occupation levels which confirm the origin of a trove of bronze weapons from Soloi reportedly taken from Soloi to Berlin at the beginning of the 20th century (Bing, 1968: 108–13, 117–18; Yağcı, 2001, 159–65; *cf* Yağcı, 2000; 2001; 2002; 2003a; 2003b). Bing suggested that the Hittite-era harbour at Soloi furnished Bronze Age traders access to important timber and metal resources in the Taurus Mountains directly behind the site (1968: 117). Soloi was later colonized either by Argives or, as seems more likely, by Rhodians from Lindos (Erzen, 1940: 71, n.118; Jacoby, 1950: IIIB, 510; Roebuck, 1959: 64, 112; Blumenthal, 1963: 106; Bing, 1968: 108–13, 117–18). It was one of several settlements in the immediate area, the most dominant being Tarsus (Bing, 1968: 110).

Although Tarsus was situated 9 km inland, it was located on a river which enabled it to become an important harbour for seagoing ships. Tarsus remained the dominant harbour of the region during the Assyrian era, when it served as a provincial capital and naval base (Bing, 1968: 117–18). Despite the presence of the Roman harbour at Soli, Tarsus re-emerged as a medieval naval base (Fahmy, 1966: 56–63). The size of this base is indicated by the success of its forces; in 904 AD Muslim forces from Tarsus seized Antalya, killing 5000 and capturing 60 Byzantine ships which they loaded with prisoners and booty. The same forces attacked Thessalonica, Cyprus and Egypt. Tarsus remained in Muslim hands until 965 AD, when it was retaken by Nicephorus (Pryor, 1988: 102–03).

Within the wider metropolis of modern Mersin a cluster of large ancient mounds can be seen near the shore, none closer than Soloi. Kazanli, east of Mersin, is of pre-Classical date (Seton Williams, 1954: 121–74). Tirmil Tepe, in the industrial quarter of modern Mersin; exhibits a large fortified tower of medieval date, while its ceramic and lithic remains indicate continuous occupation throughout the ancient and medieval periods. Yumuk Tepe likewise shows continuous occupation from the Neolithic to the Middle Ages; it stands on the Soğuk Su River not too far from Soloi (for the topographical limitations of Greek harbours in the Mersin vicinity see Blumenthal, 1963: 121).

These neighbouring mounds, each of them situated beside a river, need to be borne in mind when considering the importance of the harbour at Soloi during the pre-Roman era. Although references are limited, neighbouring harbours such as Anchiale, Zephyrium and Tarsus, received greater notice than Soloi in Classical and Hellenistic sources. Most of our information arises from movements by the Diadochoi to and from Kyinda, the Macedonian treasure-fortress situated in the mountains somewhere behind Mersin (Anchiale) (Simpson, 1957: 503–04; Sayar, 1995: 279–82). In 318 BC Ptolemy sailed with a sizeable force to Zephyrium to urge the commanders of Alexander's Silver Shields and the treasurers guarding the fortress at Kyinda to abandon the cause of Eumenes of Cardia (Diodorus Siculus, 18.62.1). In 302 BC Antiochus Monopthalmos marched from Syria to Tarsus to extract funds for his march into Cappadocia (Diodorus Siculus, 20.108).

These references to the use of multiple harbours indicate that no one harbour was truly dominant, possibly because harbourage in the Mersin vicinity was determined by a changing landscape. The rivers which empty into this narrow plain have historically shifted beds, posing sedimentary problems for river-mouth and lagoonal harbours. Soloi was celebrated in the late Hellenistic-early Roman era for its cultural accom-

Figure 1. Location plan. (C. Brandon)

plishments (the Hellenistic philosophers Chrysippus and Aratus both originated from Soloi), but there is little evidence that it functioned as a major harbour. The town was ravaged during the Mithradatic wars (89–81 BC), and its population was relocated to another settlement by Tigranes of Armenia in 83 BC (Cassius Dio, 36.20; Strabo, 14.5.8; Jones, 1971: 194). In 67 BC Pompey the Great restored the city and colonised it with survivors from his successful campaign against the Cilician pirates. He re-named the site Pompeiopolis. Pompey settled his captured pirates at Soli, at Epiphaneia in eastern Cilicia, at Dyme in Achaea, and possibly at Tarentum (Magie, 1950: 1180, n.43; Ormerod, 1987: 240–41). The site of Issos/Kinet Huyuk appears to have been abandoned at this time; possibly because Pompey's people relocated the settlement to nearby Epiphaneia (Rauh, 2000, 162–86, n.39; Tobin, 2004).

Roman hydraulic concrete

Since the harbour installations visible today date to the Roman period, we will subsequently refer to the site simply as Pompeiopolis. The portion of the harbour still well preserved presents an atypical example of Roman maritime engineering in which well-clamped ashlar masonry encases a hydraulic concrete core. Although founded in part on a natural reef, it was largely an artificial harbour laid out to a symmetrical geometric design.

The ability of Roman engineers to cast concrete under water was one of the most extraordinary achievements of the Empire. Hydraulic concrete allowed harbours and other elements of maritime infrastructure to be constructed efficiently and economically at marine sites where construction would otherwise have been difficult or impossible. This material was also used both on land and in the sea to signify status, a visible statement of Roman power and ingenuity. After its first appearance in the late-3rd century BC in the Gulf of Pozzuoli, this technology rapidly spread to the far ends of the Mediterranean between the 2nd century BC and the 2nd century AD. The final version of the harbour of Pompeiopolis was built during the florescence of this technology, some time between the end of the 1st and the middle to late decades of the 2nd centuries AD.

The Roman concrete used for underwater construction consisted of a mixture of slaked lime, pozzolana and aggregate. Pozzolana, a particular type of volcanic ash found near Puteoli in the Bay of Naples, was composed of particles rich in aluminosilicates and shaped such that they had large surface areas. These particles reacted with lime in the presence of water to produce a series of hydrated calcium aluminates and silicates which caused the mortar to set into a solid mass with the aggregate, even in the absence of atmospheric carbon dioxide, a situation characteristic of underwater structures. The aggregate (*caementa*) was added to increase the compressive strength and reduce the amount of mortar needed (Oleson *et al*., 2004: 219).

Brandon, Hohlfelder and Oleson established the Roman Maritime Concrete Study (ROMACONS) in 2001 in order to answer questions about the nature of that material, in particular its composition, the sources of the reactive ingredient (pozzolana), and the methods by which it was prepared and then placed in submerged forms. The objective of the study has been the sampling and analysis of hydraulic concrete used in maritime settings, in order to develop a detailed and extensive database based on consistent and comprehensive protocols of chemical and mechanical testing. To date a total of 63.6 linear metres of core-samples have been collected from concrete structures at Portus (Claudian and Trajan harbours), Anzio, Cosa, Santa Liberata, Baia, Portus Iulius, and Egnazia in Italy, at Caesarea in Israel, Alexandria in Egypt, Chersonisos in Crete and Pompeiopolis in Turkey. Articles and interim reports have been published in a number of specialist journals (see Brandon *et al*., 2008: 379 and Gotti *et al*., 2008: 590 for full project bibliography). We had long hoped to be able to take core samples from a Roman harbour in Turkey, and in 2009 the opportunity presented itself through the kind collaboration of Remzi Yağci.

The harbour

The harbour of Pompeiopolis had two opposed, curving moles 320 m long and *c*.23 m wide, set 180 m apart, which joined on the landward end in a semicircle. The seaward ends curved inwards to frame the harbour entrance (Fig. 2). Most of the eastern mole has now disappeared, and the landward half of the moles is surrounded or covered by silt and sand. The shape of the harbour was first illustrated in the modern era by Sir Francis Beaufort who surveyed the southern coast of Turkey between 1811 and 1812 (1817: 248–56) (Fig. 3). Although the harbour has continued to deteriorate and has in part been built over since it was recorded by Beaufort, it is still possible to make out its plan from aerial photographs, and a substantial section of the western jetty survives in surprisingly good condition (Fig. 4). Further along the coast the enormous delta of the rivers Ceyhan Nehri and Seyhan Nehri near Adana is evidence of the massive quantity of silt flowing into the sea in this region and swept continuously towards Pompeiopolis by the prevailing easterly currents. At some point well before Beaufort's visit the harbour had become completely clogged with sand and had fallen out of use. Beaufort's plan shows the site much as it is today, with over three-quarters of the basin landlocked and sand-dunes covering most of its western side.

The western mole is the better preserved of the two, although only 160 m of it is now visible. The curved outer head lies in ruins, scattered on the sea-bed, while the landward length is buried under sand and under the road skirting the ancient basin. The western section

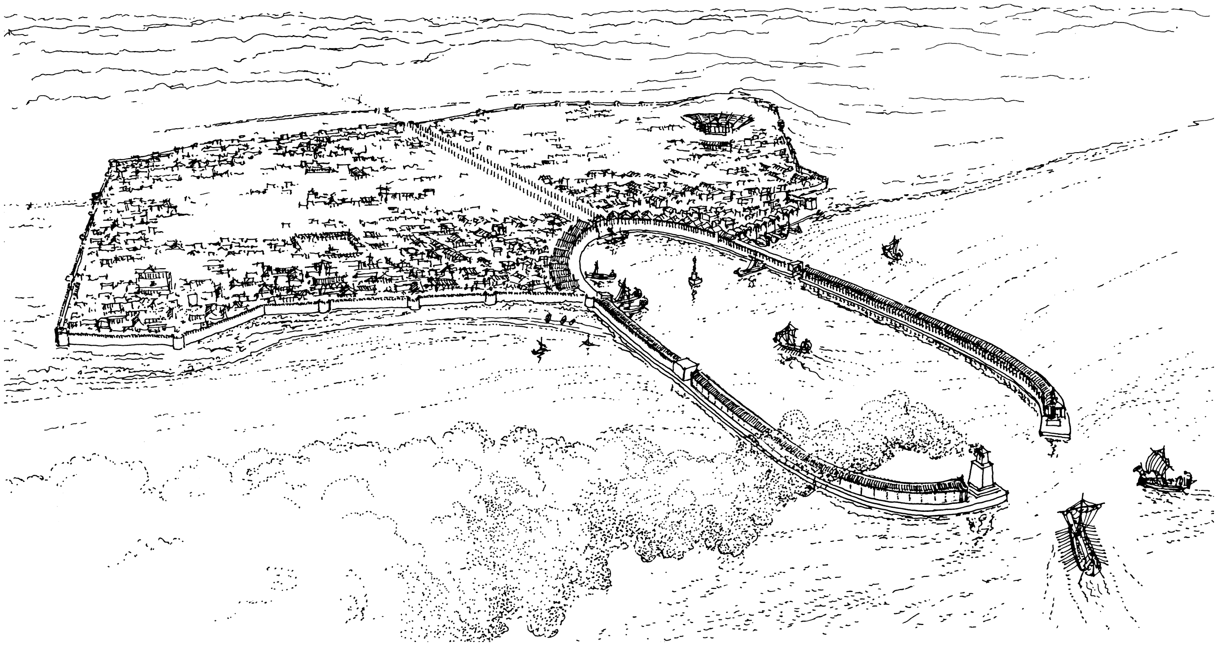

Figure 2. Sketch impression of the 2nd-century-AD harbour. (C. Brandon)

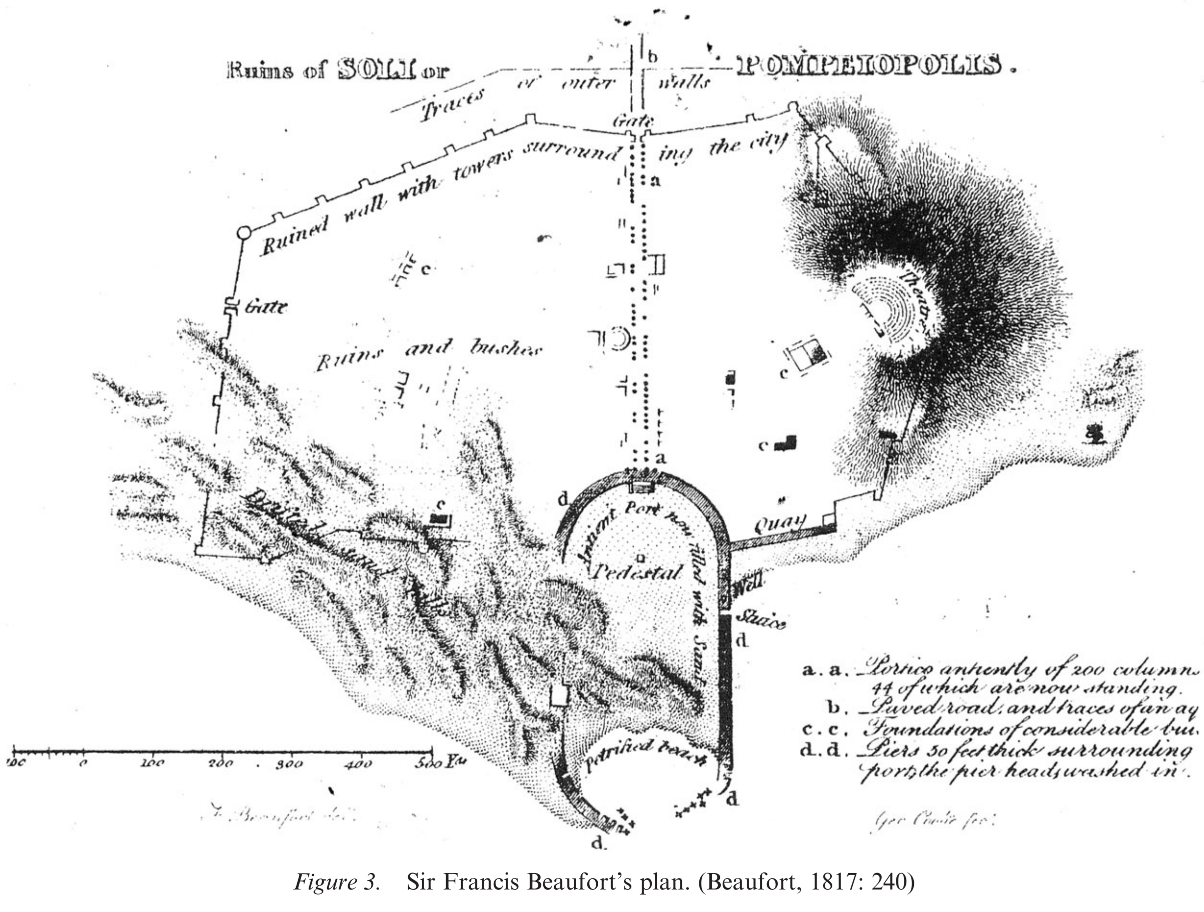

Figure 3. Sir Francis Beaufort's plan. (Beaufort, 1817: 240)

Figure 4. Aerial photograph. (courtesy of Dr Remzi Yağcı, with overlay by N. Rauh)

which still stands in the sea has survived because it was founded on a natural reef, while the eastern arm was built on sand. The absence of a firm foundation for this structure allowed its seaward length to collapse and essentially disappear. The sea-bed in this area is now strewn with ashlar blocks and rubble and there is no visible coherent structure.

Both moles were framed on the outside by double walls of ashlar masonry. Cross-walls constructed at irregular intervals divided the area into large boxes to be filled with hydraulic concrete, a type of permanent ashlar formwork. The lower portions of the outside walls appear to be up to 2.8 m thick, constructed with approximately-uniform stone blocks 1.6 m long by 0.6 m wide and 0.6 m deep. A well-preserved section of the outer wall of the western mole clearly shows the layout of a course of stone blocks (Fig. 5). The design consists of two outer and inner stretcher blocks laid on either side of five headers followed by a double row of headers. The courses above appear to step in slightly, reducing the wall-thickness to 2.2 m while maintaining a vertical outer face. A distinctive feature is that each block was secured to the adjacent blocks with large butterfly-clamps set into the upper surface of the stone (Fig. 6). No clamps have survived, but deep cuttings remain visible, 35 cm long by 5 cm deep, and varying in width from 6 cm at the ends to 3 cm at their midpoints. There were up to 6 clamps per block. The extraordinary size of the clamp-sockets suggests that the clamps were of wood rather than metal (Vann, 1994: 72).

Figure 5. Ashlar marginal wall. (ROMACONS)

The upper surface of the western mole is 1.8 m above sea-level, and where stretches of the original paving-stones remain, they are 1.3 m long and 0.63 m wide, laid out in alternating rows of header and stretcher. Four cross-walls are clearly visible on the exposed surviving length of the western breakwater, set at 34 m, 30 m, and 14 m apart to form the cells into which the concrete was placed. Most of the cross-walls are 1.6 m thick, built with alternating courses of headers and a line of double stretchers alternating with a header. One cross-wall on the landward end is only 60 cm thick on the upper course, consisting of a single line of stretchers, while it widens to a double row of stretchers at a lower level. The cells were probably built out into the sea one-by-one and in-filled with concrete as each was completed (Fig. 7). This form of enclosure was not watertight, and the compartments would have

Figure 6. Clamp-cuttings in blocks, scale in 10-cm increments. (ROMACONS)

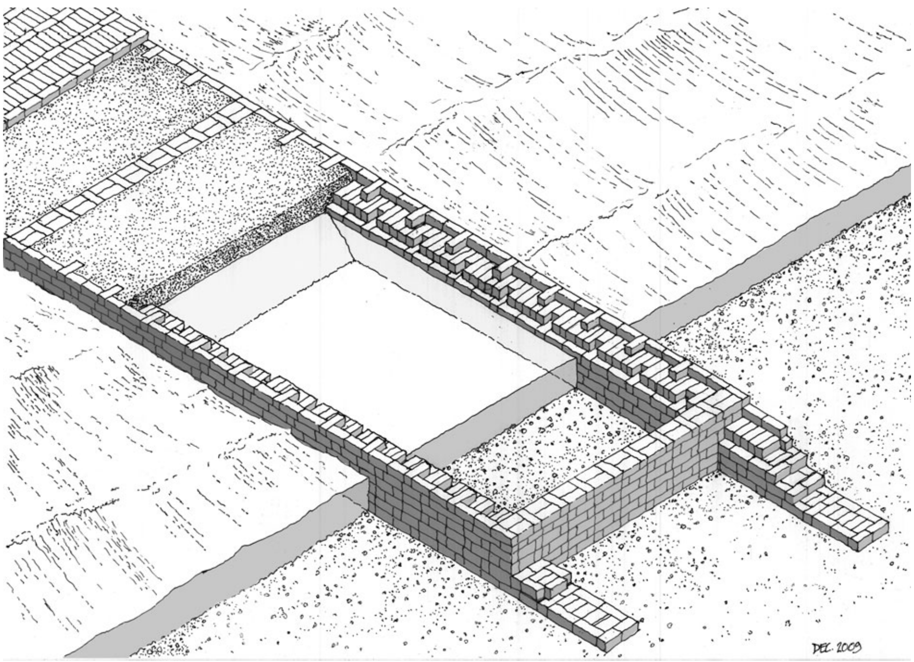

Figure 7. Reconstruction sketch of concrete laid in ashlar permanent formwork. (C. Brandon)

flooded to sea-level, requiring that the lowest stratum of the concrete be laid under water. The upper layer in each cell was then filled with what appears to be a poorer-quality concrete, ultimately paved with stone slabs.

This type of construction, comprising heavily-clamped ashlar marginal walls encapsulating a concrete core, is similar to that found on part of the harbour mole at Kyme, on the Aeolian coast of Turkey near the modern town of Aliaga. A significant difference, however, is in the width of the enclosing walls: at Pompeiopolis they are 2.2–2.8 m thick, compared to just over 1 m at Kyme. The difference is possibly explained by the use of vertical dowels which tied each course together at Kyme, leaving multiple sockets cut into the top and bottom faces of many of the blocks (Esposito *et al.*, 2002: 22–32). There are no such cuttings at Pompeiopolis, and the horizontal restraint was probably achieved by the increased width and mass of the core and the marginal walls.

Beaufort's plan shows the colonnaded street, which is still visible today, running inland from the harbour along the central axis of the basin. Aerial and land surveys now show that the street was not on axis with the harbour, but off-centre by some 20 m to the east. This was obviously a deliberate design decision, but one that seems perverse when set in the context of the geometrical symmetry of the harbour basin. This deviation from symmetry would, however, make sense if at some stage the Mezitli River, or a canal leading

Figure 8. Bronze coin of Antoninus Pius, reverse type. (American Numismatic Society)

from it, ran through the city and flowed into the harbour.

Our study has shed some additional light on a bronze coin, struck some time during the reign of Antonius Pius, which featured the harbour of Pompeiopolis as its reverse type (Fig. 8). This remarkable and rare issue was the focus of a detailed, valuable article by A. A. Boyce (1958). In this she discussed the general iconographic traditions for harbour types, the particular architectural features of this Pompeiopolis issue, the possible identification of the reclining male deity which consumes much of the space between the two breakwaters in the reverse field (*Oceanus* or a local river god?), and other aspects of this unique coin and the harbour it represented.

Boyce's preferred date for the issuance of the coin was AD 143/44, 209 years after the founding of Pompeiopolis in 66/65 BC (1958: 68, n.6). Her reasoning was based on the date of 209 which appears on the reverse (a theta followed by a lunate sigma), which she took to indicate the years which had elapsed between the renaming and refounding of the city by Pompey and the striking of this coin. It seems an unusual time to honour the city's founding, but she suggested that Hadrian possibly began a renovation of the harbour, perhaps to celebrate the bicentennial of the city's foundation, but this was only completed in the reign of Antoninus Pius, his adopted son (Boyce, 1958: 72). Both emperors were interested in the maritime infrastructure of the empire and were particularly known for their patronage of harbours. In addition to the date that appears above the statue adorning the western breakwater's terminus, the rest of the reverse field is very busy, with practically all the remaining space filled with inscriptions, letters or representation of structures which once stood on the breakwaters. Unfortunately all evidence of these architectural features has vanished either through robbing for pillage or recycling, or through the destructive force of nature over the centuries.

ROMACONS did provide a chronological confirmation for the construction of the breakwaters. C14 analysis of a wood-fragment found in our core-sample (POM.2009.02) was carried out by the Oxford University Research Laboratory for Archaeology and Art History and yielded a Calendric Age calAD: 147 ± 48 (OXA-21197), which coincides nicely with Boyce's theory regarding the start of harbour renovations in the reign of Hadrian and their completion and formal dedication later under Antoninus Pius. Although there is a congruence of numismatic evidence and C14 date for a single sample of wood, one cannot use this datum to provide a firm chronological sequence of stages of the harbour construction. But what is now certain, and was not when Boyce published her article, is that the harbour ruins visible today date from some time in the mid-2nd century AD, and not from any time significantly before the issuance of the coin. In other words, the two surviving but ruinous breakwaters seem to date from the Hadrianic/Antonine eras and not from any harbour installations constructed when Pompey re-established Soli as the city that bore his name.

The beginning of a major harbour construction project by one emperor and its completion by his successor was not unique to Pompeiopolis. Boyce mentioned that a similar situation occurred at Portus, the harbour complex near the mouth of the Tiber. There construction started during the reign of Claudius (AD 41–54), but a commemorative coin with the harbour as a reverse type was not issued until late in Nero's reign. Imperial Rome's new harbour was clearly functioning before the coin was struck in AD 64, but perhaps all the maritime structures built around the harbour had not been completed before that year, or, more likely, it was struck that year to announce the completion of harbour repairs by Nero following the natural disaster which caused the sinking of 200 ships within the harbour in AD 62, and to signal to the Roman world that the imperial harbour was once again fully functioning.

Another point which emerged from our study was that a river, now known as the Mezitli River, once debouched into the sea where the Roman harbour stood. Our coring uncovered river alluvium in the vicinity of, and possibly under, the western breakwater. It may well have been that throughout its Roman existence the river flowed next to or beneath the colonnaded street which led from the city to the harbour itself. Since the river's mouth either existed where the harbour was later built or was still within its confines, the reclining figure on the reverse type may well be a personification of a local river-god, or *Portunus*—a deity associated with the harbour itself, or *Oceanus*, or possibly all three. A figure honouring three divine manifestations for river, harbour and ocean might well have been intended to show the interconnectedness of all these elements in the prosperity of the city. If so, this iconography ingeniously captured the role of this harbour as a maritime gateway for the region it served.

Boyce's identification of the structure at the end of the western or lower breakwater on the coin as a lighthouse seems very likely, although no trace of such a structure exists today. Boyce's suggestion that this structure could have been an altar seems much less likely, as large altars at the termini of breakwaters are otherwise unknown (Boyce, 1958: 68). One would expect a lighthouse to have been located precisely at the mouth of a harbour. But if Boyce is correct in that assumption, her explanation that a series of 'jar-like objects' which adorned the two-storied structures which stood on the breakwaters were possible fire-beacons to mark the harbour or to assist navigation into the harbour in bad weather seems less likely (1958, 68). Such beacons would have been difficult to operate and maintain and would have been redundant, given the proposed location of the lighthouse. A lighthouse would have served to guide ships to the harbour entrance, and in difficult weather it is not likely that any large vessel unfamiliar with the quirks of the Pompeiopolis harbour would have attempted to enter it under sail. Local rowed tenders or tugs would more probably have guided these vessels to safe moorings within the harbour regardless of sea conditions. We did not find any of these jars in our brief study, and, even more unfortunately, no evidence of any harbour structures on which they once may have stood has survived. Boyce also suggested that what she called a 'feather-shaped object' located between two of the 'jars' might have been a sail, placed on top of the second storey of the structure on the east breakwater to indicate the direction and relative velocity of the wind (1958: 69).

This Antonine coin does not display two features which appear in Beaufort's plan of the harbour (Fig. 3). One was a putative statue-pedestal at the back of the basin close to the point where the river might have entered the sea. No evidence for such a structure is visible today, and its proposed location now seems to be covered by earth. Did the pedestal really exist, or was Beaufort wrong a second time in his sketch-map, as he clearly was when he showed the colonnaded street leading to the harbour on axis with it? Was this pedestal added some time after the coin was struck, or was the statue which stood on it too insignificant to attract the interest of the die-engraver of this coin? There are no discernible answers to these questions.

The other feature missing from the coin representation was a break in the eastern breakwater which Beaufort identified as a sluice-gate, intended to allow water moving from east to west in the current that runs offshore to enter the enclosed basin to help reduce siltation. No identifiable trace of its existence appears in the washed-out sections of the eastern breakwater, although, as with the hypothetical statue-pedestal, it may await discovery beneath the alluvial fill which now covers much of the ancient harbour basin. These two disconnects between the coin-type and the 19th-century plan are mysteries that defy easy resolution.

The core-samples

ROMACONS's tried-and-tested method for sampling Roman concrete involved the use of a standard diamond core-drilling rig, as used by the construction and civil-engineering industries, adapted over the years to be able to take concrete cores 10 cm in diameter and up to 6 m long which produce a complete stratigraphic section through the structure (Oleson *et al.*, 2004: 208–10). Hydraulically powered, the rig can operate both above and below water. In this instance we only worked above water on top of the west mole, since the top surface of the mole is currently 1.8 m above sea-level. The structure is so well preserved that we were able to drill down through its complete height and well into the bedrock foundation (core POM.2009.01). The coring was carried out over two days, on 13 and 14 August 2009.

The first core, POM.2009.01, was drilled 5.7 m in from the west face of the structure, 13.2 m from cross-wall 01, and *c*.5 m north of a point where bedrock protrudes through the constructed part of the mole (Fig. 9). The upper layers were very difficult to drill through due to the friable nature of the binding mortar and the very hard, large aggregate composed

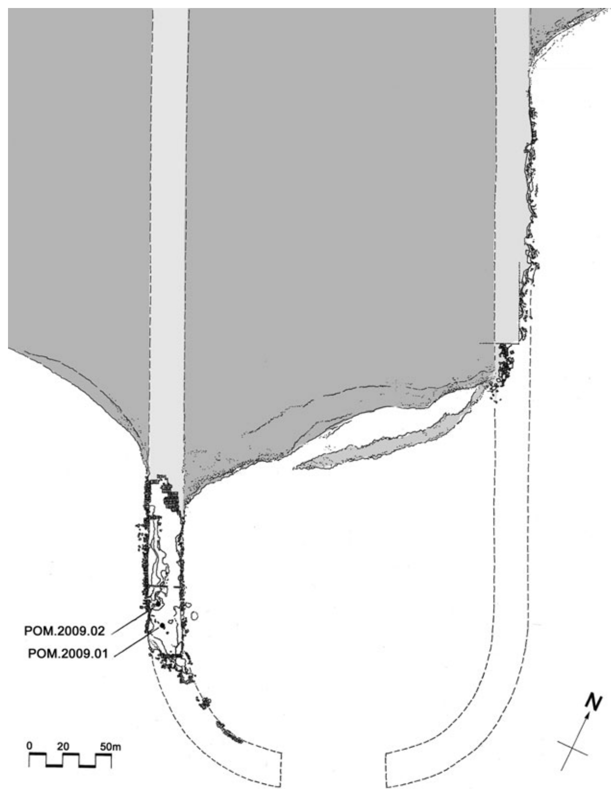

Figure 9. Plan of harbour. (C. Brandon, after Vann, 1994, 69 fig. 2)

of closely-packed, smooth river-bed cobbles and pebbles, *c*.15–20 cm in diameter. The overall length of the core was 4.44 m. The mortar in the top 0.75 m is a poorly-mixed, very pale brown material (10YR 8/4) which is fairly soft, containing much micro-aggregate and many pebbles *c*.4–18 mm in diameter. The micro-aggregate consists of rounded sea or river sand, including many grains that are red, green, and blue. There are also many white nodules 4–8 mm in diameter which are either un-mixed lime or a product of the long-term reaction of the lime with the pozzolana, and also some small fibrous nodules which could be pumice, brownish-yellow in colour (10YR 6/6). There is a laminar deposit across the core at a depth of 0.15 m below the top surface, either a product of the evolution of the mortar, or laitance created during the pour. From –0.75–0.95 m the mortar was mostly ground away by the coring, although several hard river-stones remain, and some pumice lapilli, 20–30 mm in diameter.

From –0.95–1.4 m the mortar is a very-light-grey to white, with limestone and other smooth cobbles as aggregate. There are small fibrous pumice inclusions and much rounded sand micro-aggregate, some brightly-coloured as noted above. At a depth of –1.35 m there is a rounded lump of volcanic tuff, light-greenish-brown in colour (10YR 7/6) with yellow-brown (2.5Y 7/4) inclusions. From –1.4–2.2 m, the mortar was the same type as above. Although poorly compacted, it nevertheless is quite hard and varies in colour from white to light-green. The change in colour and composition may have to do with the proximity of the water-level. There are many voids in the material and many large white nodules, along with lumps of fibrous pumice and particles of green sand, possibly olivine. Below –2.2 m the core consists of a yellowish-red-to-pink limestone bedrock with a layer of very fine mud just above it. It was impossible to determine precisely where the mud came from, because it infiltrated the core-hole each time the tubes were removed to take out the cores. There are no apparent fissures in the rock that could have contained the mud, so it probably had been deposited on top of the bedrock by the river that flowed into the basin or harbour which preceded the Roman mole.

Core POM.2009.02 was taken on top of a flat concrete surface 0.49 m above sea-level, and inside the line of the blocks framing the upper part of the mole, 3 m from cross-wall 02 and 3.1 m from the western marginal wall's outer face (Fig. 9). The level surface seems to be the top surface of the lower level of hydraulic concrete, exposed by erosion of the upper level of concrete after the outside ashlar wall was breached at this point. The core-hole depth was 0.9 m, although only 0.8 m of material was recovered. The mortar is clearly pozzolanic in character, even containing some tuff aggregate. This same type of tuff is seen in the Italian and Caesarea cores, and it probably arrived as an accidental component of the pozzolana sand shipped from the Puteoli area. The piece of limestone aggregate which forms the bottom of the core appears weathered and does not show any traces of adhering mortar, so it probably represents the bottom surface of this layer of concrete. The core-tube went *c*.1 m beyond this point, seemingly going through layers of hard and soft material, and jamming frequently. Nothing was recovered from this layer, which may have consisted of a rubble footing.

The mortar is very homogeneous throughout the core: very hard, well mixed, and clearly containing much pozzolanic material. The mortar of the upper portion is a yellowish-brown colour (10YR 5/6), drying to a very pale brown (10YR 7/4). It contains many nodules of pumice, 11–18 mm in diameter, and many angular fragments of a white material, 2–10 mm across, that are either unburned limestone, un-mixed lime, or a product of the pozzolana-lime reaction which has occurred over time. The mortar is well compacted, but there are numerous very small spherical voids 1–3 mm across, perhaps resulting from some circumstance during placement, or from the chemical evolution of the mortar. The aggregate consists of the same round river-bed limestone cobbles as noted in the first core, with occasional lumps of tuff 23–53 mm in diameter. The tuff also contains nodules of pumice. Wet, the tuff is greenish-blue in colour but dries to a light yellow-brown (2.5Y 6/4). There is no sign of the coloured sand particles seen in the upper portion of Core 01.

From –0.33 to –0.7 m there is a rapid change in the colour of the mortar, to a bluish-green colour or possibly greenish-grey (Gley 1 6/5GY), drying to a light greenish-grey (Gley 1 7/10Y). At –0.7 m the mortar returns to its brownish colour. In our other cores of pozzolanic mortar, the bluish-green colour is typical of mortar exposed to sea-water, or kept moist by sea-water infiltrating the block. At –0.65 a small fragment of fibrous material, possibly a reed or twig, 6 mm in diameter, was embedded in the mortar. At –0.75 m a small fragment of wood was embedded in the surface of the core. It was extracted and sent for C14 analysis. After the cores were extracted, the holes were filled with inert sand and sealed with a weak hydraulic lime mortar, and parts of the top sections of the cores and river-cobble aggregate were reinserted as a cap to the filled core-holes.

It is apparent from the initial visual inspection that there are two distinctly different concretes, the lower layers of a clearly hydraulic material and the upper layers of a lime or weaker pozzolanic lime mortar. Chemical and thin-section analysis will confirm the specific make-up of each. One very marked difference between the Pompeiopolis concrete and that we have studied at other sites is in the proportion of large aggregate to mortar. We have found that percentages range around 40% aggregate to 60% mortar in the concrete sampled at sites along the Italian coast, Alexandria and Caesarea, whereas at Pompeiopolis the percentage varies from 64 to 54% aggregate and 36 to 46% mortar. This ratio is more akin to that found in Roman terrestrial structures (DeLaine, 1997: 123).

In line with the analysis and mechanical tests which have been carried out on previous ROMACONS concrete samples; the cores have been taken to Italcementi's research laboratories in Bergamo, Italy. There they are being studied with an agreed set of protocols which include X-ray fluorescence spectroscopy (XRF), X-ray diffraction (XRD), scanning electron microscopy with X-ray micro-analysis (SEM EDS), differential scanning calorimetry and thermo-gravimetric analysis (DSC TGA), petrographic analysis, mercury intrusion porosity analysis, compressive-strength testing and measurements of Young's Modulus and density. All the data from the 2009 season will be added to that collected from earlier work and will be published in a final report which is currently being prepared.

Christopher Brandon
Pringle Brandon Architects, 10 Bonhill St, London, EC2A 4QJ, UK

Robert L. Hohlfelder
Dept of History, University of Colorado, Boulder, CO 80309–0234, USA

John Peter Oleson
Dept of Greek and Roman Studies, University of Victoria, Victoria BC V8W 3P4, Canada

Nicholas Rauh
Purdue University, W. Lafayette, IN 47907–2039, USA

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Ancient Harbour Structures in Croton, Italy: a reappraisal of the evidence

Dr Jeffrey G. Royal recently published in this journal (2008) the discovery of apparent remains of two submerged harbours and the walls of two buildings which sank in the sea off Croton, southern Italy. After having worked with Royal in Croton in the summer of 2005, and continued the research in 2006, this author has been able to collect further evidence which leads to different conclusions. The harbour IT05-AA is more likely to represent what is left *in situ* of a Roman *navis lapidaria* after most of its artefacts were raised in 1915. The two sites IT05-AB and IT05-AD, which Royal interprets as ruins of submerged walls of the Greek temple of Hera Lacinia, also appear to be remains of shipwrecks with cargoes of marble. No new information is available regarding the 13-m-deep breakwater of supposed Greek Archaic age (IT05-AE/AF), but its depth does not correspond well with a submerged calcarenite quarry in the same area, which is only 6 m deep and is tentatively dated to between the Archaic and Hellenistic periods. While Royal's contribution to the study of Croton's maritime history remains useful, and his 2005 survey is important for its documentation of the area's archaeological heritage, this note aims to rectify some of his conclusions in the light of updated field data.

Figure 1. General extension of the survey area: Croton and Praialonga, along with the other places mentioned in the text. (D. Bartoli)

The 2005–2006 research seasons

In the summer of 2005 Francesco Prosperetti and Annalisa Zarattini, heads of the Soprintendenza per i Beni Archeologici della Calabria, granted the Institute of Nautical Archaeology at Texas A&M University (INA) and RPM Nautical Foundation (RPM) permission to survey the sea between the harbour of Croton and Praialonga, along the Ionian coastline of Calabria (Fig. 1). Royal and this author co-directed the project on behalf of RPM and INA respectively. The search area, along some 40 km of coastline, in waters between 5 and 75 m deep, was chosen after a preliminary study of historical, archaeological and geological data attested to the relevance of Croton and the nearby promontory of Capo Colonna to navigation in antiquity (the Panhellenic sanctuary sacred to Hera was built at the tip of the promontory which closes the Gulf of Tarentum, and was the most important landmark for ships coming from the east). Also important was the low sedimentation rate, which would facilitate visual identification of potential ancient sites on the sea-floor. The absence of seasonal rivers, called

