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The Roman Maritime Concrete Study (ROMACONS): the harbour of Chersonisos in Crete and its Italian connection

Étude du ciment hydraulique romain : le port de Chersonisos (Crète)

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Abstract *- Vitruvius stated that it was necessary to use pozzolana from the Naples region in Italy to make hydraulic concrete that could set underwater. How extensive was the use of this particular material? We know that pozzolana was shipped across the Mediterranean from Italy to Israel for the construction of the major harbour of Caesarea. But did the Romans also export it to minor cities such as Chersonisos in Crete to build the concrete moles for its harbour? The Roman Maritime Concrete Study (ROMACONS) was established to answer these questions and others related to the use by the Romans of this extraordinary technology.*

Résumé *- Depuis Vitruve, il est admis que l'utilisation de la pouzzolane provenant de la région de Naples est indispensable pour fabriquer du ciment hydraulique à prise dans l'eau de mer. Notre article pose différentes questions concernant l'importance de l'utilisation de ce matériau et de cette technologie révolutionnaire. Si de la pouzzolane a bien été exportée vers le grand port de Caesarea (Israel), qu'en est-il vraiment de plus petits ports comme Chersonisos en Crète ? Le projet ROMACONS (Roman Maritime Concrete Study) a pour objectif d'étudier le ciment maritime romain en Méditerranée et tente de répondre à ces interrogations.*

Sometime between 30 and 20 BC Marcus Vitruvius Pollio wrote a treatise on architecture in which he explains how harbours should be built at sites where there is no natural shelter (ROWLAND and HOWE, 1999). He described how to construct underwater concrete foundations and structures that would form the artificial enclosing arms for harbours. Pre-Roman solutions generally included rubble or ashlar block breakwaters and moles. Although these methods continued to be used throughout the Roman era, another technique was introduced that revolutionised the design of harbour and other maritime structures – the use of hydraulic concrete. This material, which could be cast and set underwater, began to be used in harbour structures sometime in the second century BC (GAZDA, 2002). Roman architects and engineers were free to create structures in the sea or along shorelines that previously would have been difficult if not impossible to achieve. The active ingredient that reacted with the lime to form the hydraulic variant was pozzolana or volcanic ash and made what we now call a pozzolanic concrete or mortar. Probably by accident Roman builders found that when volcanic ash sand from quarries around the Bay of

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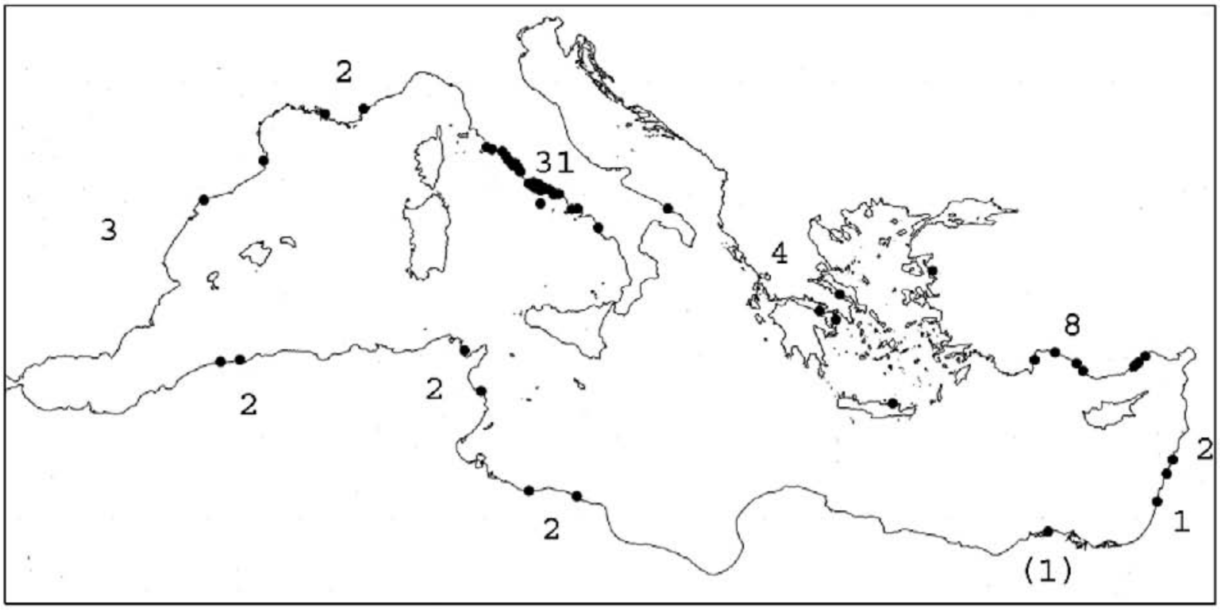

FIG. 1 - MAP OF THE MEDITERRANEAN WITH THE LOCATION AND NUMBER OF ROMAN MARITIME SITES

Pozzuoli was mixed with lime, it made a stiff mortar that could be laid and cured underwater. Contained within formwork and laid in layers with large lumps of stone or tuff aggregate, it would set into a solid mass that has proved to resist the ravages of the sea for over two thousand years. Unlike ordinary lime mortars made with hydrated lime and inert siliceous sands that react with carbon dioxide in the air to reform into «man-made» limestone, pozzolanic mortars are made with a highly reactive aluminosilicate component (pumice and volcanic ash) that when mixed with lime generates reaction products that take the form of gels; rods; fibres and plates that give strength and bind all the materials together[1] (LECHTMAN and HOBBS, 1987). Vitruvius recommends that when building structures of concrete in the sea, the pozzolanic material should ideally be taken from around the Bay of Pozzuoli. We now know that the Romans were prepared to transport and ship this material for thousands of kilometres in order to ensure that they could use this technology (HOHLFELDER, 1999). In 1991, chemical analysis carried out by OLESON and BRANTON on the pozzolana used in the concrete at the late first century BC Roman harbour of Caesarea Palestinae found that it had been shipped in bulk freighters 2000 km from the Bay of Naples (OLESON and BRANTON, 1992). The only shipwreck that is known to have carried a load (secondary cargo) of pozzolana from the Naples area was the large Roman merchant vessel that sank around 75-60 BC off the harbour of Madrague de Giens in the South of France[2]. How widespread was this trade and the use of Vesuvian ash-based pozzolanic hydraulic concrete? To answer this and other questions that relate to the nature of the concrete used by the Romans in maritime structures, whether harbour moles, jetties, bridge footings or fishponds, the authors established ROMACONS – The Roman Maritime Concrete Project. Our database of known sites is extensive, spreading across the whole Mediterranean, and ranges in date from the second century BC to the Byzantine era (fig. 1).

One of the first harbours investigated was the Roman harbour at Chersonisos (Hersonissos) on the northern coast of Crete. This minor Roman harbour (270 x 150 m in size) was founded on a small Hellenistic haven that was sited in the lee of a headland now called Kastri. The Roman improvements to the Hellenistic harbour comprised additional concrete moles to the rubble breakwaters to the south and east, and quays along the shore (fig. 2). We knew that the Romans were prepared to ship vast quantities of pozzolana and tuff across the Mediterranean from Italy to Caesarea in what is now Israel. But did they also export it for use in the construction of smaller provincial harbours such as Chersonisos? In 1955 and 1956 the ancient harbour of Chersonisos was surveyed by John LEATHAM and Sinclair HOOD (LEATHAM and HOOD, 1958/59). Since then a new harbour and the resort of Limin Khersonisou have developed and the majority of the Roman moles are buried under the modern marina. However, the mole to the south and the quay on the west are untouched and were the source of the samples taken in October 2001. The southern mole is preserved for a length of 22.7 m in two parts and stands within 3.3 m of water to just below sea level. Concrete quays extend along the shoreline on the west of the harbour and remain in evidence for a length of 30 m and approximately 2.6 m wide. The long «L» shaped eastern mole that now lies hidden under the modern concrete breakwater was originally 150 m long with a 30 m long return and between 5.2 to 5.3 m wide. LEATHAM and HOOD described it as being well preserved and faced with small squared blocks of stone that remained in-situ at the level of the seabed. Was this

1- Roman builders usually made lime that was free of impurities, such as clay, and it was consequently non-hydraulic.
2- Personal communication Dr Patrice POMEY, also LIOU and POMEY, 1985: 562-563.

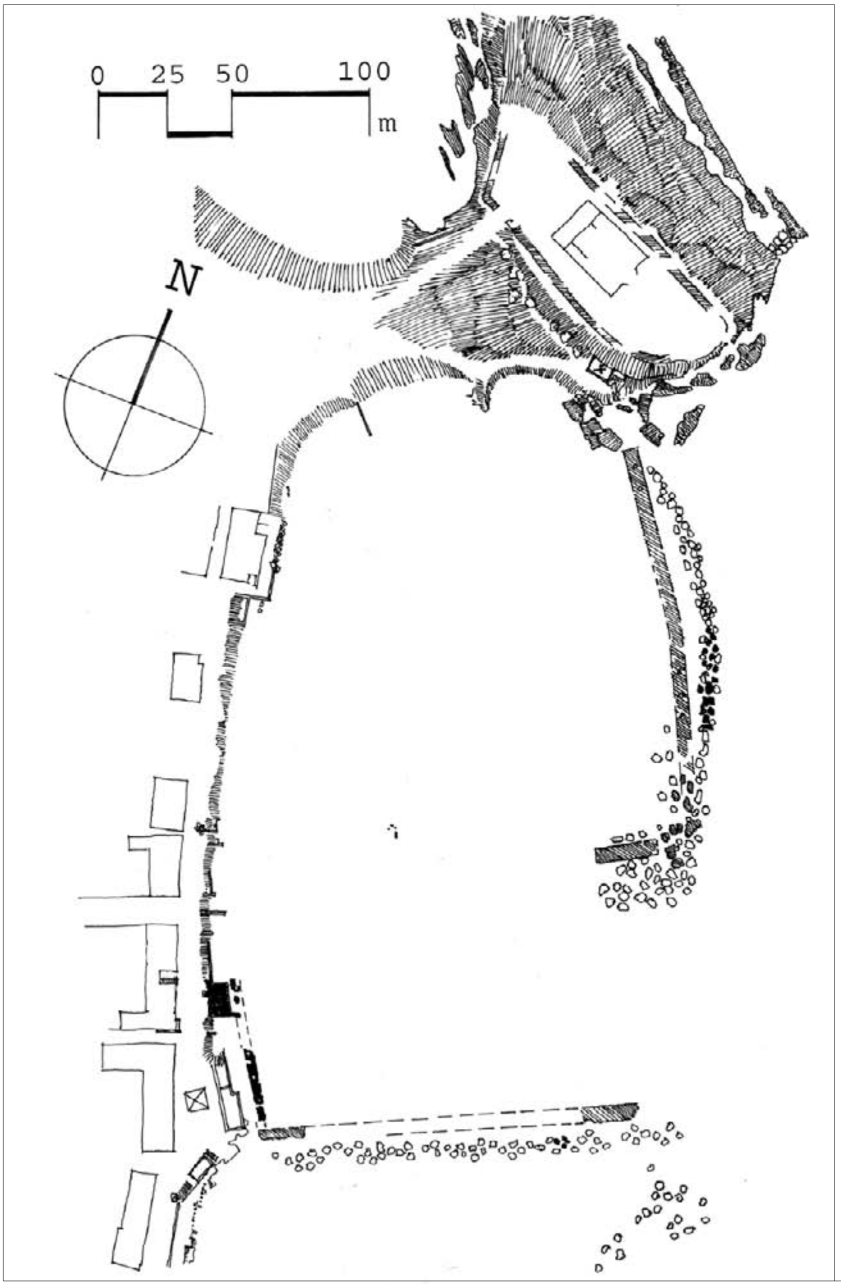

FIG. 2 - PLAN OF THE HARBOUR OF CHERSONISOS IN CRETE
(after LEATHAM and HOOD)

evidence of construction occurring within a watertight drained formwork as described by Vitruvius in situations where pozzolana was not available[3]? Along the inner surface of the mole were recorded a series of vertical recesses set at 6.8 m centres alternately 1.0 m and 1.5 m deep and between 0.6 to 0.8 m wide. These were initially thought to have been either recesses that housed wooden steps or timber fenders. It is more likely that these were the remains of the original formwork within which the concrete was cast. Was this an inundated structure where the mix of lime, pozzolana and aggregate was placed underwater, or was it a double-walled drained form that allowed an ordinary sand lime mortar and rubble fill to be placed within a stone-faced mole all built in a dry environment? The presence of pumice in a sand lime mortar does not necessarily mean that it was purposely made to be hydraulic. In Crete there is significant contamination of the soils from pumice and ash that originated at Santorini. If local sands were used in a conventional air-cured mortar, it would also have pozzolanic properties that would show up in analysis. The geological signature of any Santorini pumice or volcanic ash, however, would be distinctly different from pozzolana from Naples or elsewhere.

LEATHAM and HOOD mentioned that the original top surfaces of the moles remained in only a few places and were almost flush with the current sea level, although these too have been destroyed by modern construction. This, together with the drowned fishpond on the south-eastern tip of the Kastri headland, indicates that the relative sea level has risen approximately 1 m since the Roman era. The harbour is now fairly shallow with a maximum depth of 3 m to a sandy bottom that has obviously silted up over the course of time.

In October 2001 a permit from the Ephorate of Underwater Antiquities and the Director of Conservation allowed us to take 5 samples, 3 cm in diameter and 10 cm in length, from the remains of the concrete moles[4]. Due to the limited time available and the restriction on the sample size it was decided to collect them with steel tubes

3- In Vitruvius's Ten Books on Architecture he identifies three different types of construction, which can be summarised as follows: Type 1 was the placement of concrete within a flooded containment system; Type 2 was the casting of concrete blocks above water on the end of a pier and after they had set allowing them to settle into the sea so as to extend it; Type 3 was the placement of concrete within an evacuated watertight enclosure.

4- Chris BRANDON carried out the sampling on the 14th October 2001 under a licence granted by the Ephorate of Underwater Antiquities and the Directorate of Conservation. The British School at Athens supported the application and we are indebted to David BLACKMAN, Director of the School at the time, for his guidance and assistance. We also thank Katerina DELAPORTA and Elpida HADJIDAKI of the Ephorate of Underwater Antiquities without whose help we could not have carried out the work.

PHOTO 1 - COLLECTING CONCRETE SAMPLES AT CHERSONISOS
(Cliché : J.M.BRANDON, 2001)

driven into the concrete matrix or mortar using a 2-kg lump hammer (photo 1). Five 30-cm long hardened stainless steel coring tubes with an external diameter of 3.2 cm were individually driven into the moles at selected sites. The samples of mortar within the tubes were retained for later removal on shore and sent for analysis at the University of Colorado(5). The compact nature of the concrete in which the mortar lenses between the mainly limestone aggregate blocks was minimal compared to other sites that had been studied. Preliminary measurements indicate an average space between the large aggregate at Chersonisos to average approximately 4 cm, whereas at Nero's harbour of Antium (Anzio) it is 7.9 cm; at the Claudian harbour of Portus 11.9 cm and at the Trajan harbour of Portus 4.7 cm. This meant it was difficult finding locations on the surface of the marine encrusted remains where there was sufficient quantity of mortar that could be sampled with the hammer driven corer. In the end only fragmentary samples were collected confirming the inadequacy of this method of surface collecting concrete samples.

Microscopic examination and petrographic analyses of two thin sections cut from the light grey white mortar from a sample (CH-02) taken from the western end of the southern mole, showed that it contained aggregate clasts of:

– Both grey and yellow pumice fragments ranging between 1 and 10 mm in diameter for 30 % of the volume of the sample. Pumice consisted of clear and colourless to pale brown glass and contained crystals of feldspars, biotite, and green clinopyroxene, and vesicles that vary between rounded to highly elongated.

– Grey, red and black volcanic rock and individual crystal fragments ranging between 1 and 4 mm in diameter for 10 % of the volume of the sample. Rock fragments include both light coloured felsic and red and black mafic igneous rocks. Crystal fragments include quartz, plagioclase, biotite and green clinopyroxene, all also found as crystals in either pumice and rock fragments.

– White calcite and lime fragments ranging between 1 and 10 mm in diameter for 10 % of the volume of the sample.

– All in a fine grained matrix of mortar comprising 50 % of the volume.

The other samples of mortar had a similar make up to CH-02 and it was established that it was representative of all the concrete used at Chersonisos.

A pumice separate was extracted by hand from the consolidated sample CH-02 and analysed for chemical composition. It appears that the pumice ash contained within the mortar has much in common with volcanic material from Italy, for example a very high K2O content (>6 wt %) and total alkali element concentration (Na_2O + K_2O > 10 wt %) for a rock with an intermediate silica concentration (SiO_2 = 60 wt %). This pumice did not derive from the island of Santorini to the north, which typically would have lower K_2O (<3 wt %) and total alkali concentration (<8 wt %) even for pumice with very high silica concentration (SiO_2>70 wt %). Although it may possibly have come from the island of Kos or even Southwest Turkey, where highly alkaline volcanic rocks also occur, it more probably was sourced from Italy.

The restrictions imposed on surface collected samples severely limited the range of analysis that could be carried out. It was also apparent that Roman concrete was not homogeneous and surface samples were unlikely to be truly representative of the whole.

In 2002 ROMACONS employed a new method to collect and extract samples from Roman concrete. With the backing of Italcementi, the major Italian cement company, a purpose built coring rig was developed that could take up to 6 m long continuous concrete cores 9 cm diameter from ancient maritime concrete structures(6). This equipment can operate above and below water and can drill through the hardest limestone aggregates (photo 2). A protocol for testing these samples was agreed between the CTG Italcementi and Stephen Cramer of the University of Wisconsin which involved physical and chemical analysis that could be repeated for all cores taken(7). For logistical reasons the 2002 and 2003 seasons using the new coring rig were carried out in Italy. To-date

5- The mortar samples were analysed by Charles STERN of the Department of Geological Sciences, University of Colorado, Boulder, CO 80309-0399. USA.

6- The coring equipment, built by Cordiam S.r.l. of Como, was purchased for our use by CTG Italcementi Group of Bergamo. We are very grateful to Dr. Luigi CASSAR for his continued interest in the project and his invaluable support. The machinery consists of a hydraulically driven coring drive on a hand operated rack and pinion mount, with a separate petrol powered hydraulic pump unit connected to 25 m long high pressure hydraulic hoses. The coring drive, designed for mounting on standard construction scaffolding, rotated pipe sections 1.0 m long and 10 cm in diameter, threaded to accommodate a diamond drill bit. A small, hand held, hydraulically driven coring drill was used to prepare holes for expansion bolts that anchored the scaffolding in position. Both drills were fed with a pressurised water supply that cooled and lubricated the coring tubes, flushed out the core debris and kept the face of the diamond drill clean, even when working underwater.

7- Mechanical, chemical and geological analyses are being undertaken by collaborating scientists Prof. Stephen CRAMER (University of Wisconsin, Madison), Prof. Charles STERN (University of Colorado, Boulder), Dr Emilio GOTTI (CTG Italcementi), Dr Roberto CUCITORE (CTG Italcementi) and GBC Structural Services (UK).

PHOTO 2 - ROMACONS CORING RIG WORKING UNDERWATER
(Cliché : R.L.Hohlfelder, 2003)

12 cores have been successfully taken from the north mole of the Claudian harbour and at the entrance to Trajan's basin both at Portus near Rome; from the south-eastern breakwater at Anzio; the fishpond at Santa Liberata; and from the pilae in the harbour of Cosa (Oleson, Brandon and Hohlfelder, 2004 a-b).

It can already be seen that this method of sampling large masses of Roman hydraulic concrete has significant promise, providing a true, undisturbed stratigraphic sample of ancient concrete structures with minimal impact on their integrity, and supplying samples for a wide range of tests(8). Using this technique we hope to return to Chersonisos, as part of the ongoing ROMACONS Project. By coring the concrete moles and taking continuous stratigraphic sections we hope to confirm the preliminary findings from the 2001 season that the key raw material for the concrete was imported from the Bay of Naples. In doing so we will be adding another piece in our jigsaw of understanding this extraordinary Roman maritime technology and the shipping trade that supported it.

BIBLIOGRAPHY

Brandon C., (1996), Cements, Concrete and Settling Barges at Sebastos: Comparisons with Other Roman Harbor Examples and the Descriptions of Vitruvius, *Caesarea Maritima. A Retrospective after two Millennia,* Leiden, p.25-40.

Brandon C., (1999), Pozzolana, lime and single-mission barges (Area K), *Caesarea Papers,* 2., Journal of Roman Archaeology Supp. 35, Portsmouth, p.169-178.

Gazda E.K., (2002), Cosa's Contribution to the Study of Roman Hydraulic Concrete: An Historiographic Commentary, *New Light from Ancient Cosa, Classical Mediterranean Studies In Honor of Cleo Rickman Fitch,* American Academy in Rome, New York, p. 163.

Hohlfelder R.L., (1999), Building Sebastos: the Cyprus connection, *The International Journal of Nautical Archaeology*, 28.2, p. 158-159.

Hohlfelder R.L., (2000), Beyond Coincidence? Marcus Agrippa and King Herod's Harbor, *Journal of Near Eastern Studies,* 59, p. 241-253.

Hohlfelder R.L., Brandon C., and Oleson J.P., (2005), Building a Roman fila in the sea - Experimental Archaeology of Brindisi, Italy september 2004, *International Journal of Nautical Archaeology,* 34.1: p.125-129.

Leatham J., and Hood S., (1958/59), Sub-Marine Exploration in Crete, 1955, *The Annual of the British School at Athens,* LIII-LIV, p.263-273.

Lechtman H.N., and Hobbs L.W., (1987), Roman Concrete and the Roman Architectural Revolution, *The Ceramics and Civilization,* vol. III, p. 95-101.

Liou B., and Pomey P., (1985), Directions des recherches archéologiques sous-marines, *Gallia*, 43, p.547-576

Oleson J.P., Brandon C., Cramer S.M., Cucitore R., Gotti E., and Hohlfelder R.L, (2004a), The ROMACONS project: a contribution to the Historical and Engineering Analysis of Hydraulic concrete in Maritime Structures, *The International Journal of Nautical Archaeology,* 33.2: p.199-239.

Oleson J.P., Brandon C.J., and Hohlfelder R.L., (2004b), The Roman Maritime Concrete Study (ROMACONS): Fieldwork at Portus, Anzio, Santa Liberata, Cosa, 2002-2003, *in* F. Maniscalco, ed., *Mediterraneum. Tutela e Valorizzazione dei beni culturali ed ambientali, Vol. 4,* Tutela del patrimonio culturale sommerso - Protection of Underwater Cultural Heritages, p.185-194.

Oleson J.P., and Branton G., (1992), The technology of King Herod's harbour, *Caesarea Papers, Straton's Tower, Herod's Harbour, and Roman and Byzantine Caesarea,* Journal of Roman Archaeology Supp. 5, Ann Arbor, p.49-67.

Oleson J.P., (1985), Herod and Vitruvius: Preliminary Thoughts on Harbour Engineering at Sebastos, the Harbour of Ceasarea Maritima, *Harbour Archaeology. Proceedings of the First International Workshop on Ancient Mediterranean Harbours, Caesarea Maritima,* British Archaeological Reports, Intl Series, 257, Oxford, p.165-172.

Oleson J.P., (1988), The Technology of Roman Harbours, *International Journal of Nautical Archaeology,* 17, p.117-129.

Rowland I.D., and Howe T.N., (1999), *Vitruvius Ten Books on Architecture*, Cambridge University Press, Cambridge, p.73-74

8- The 10 cm diameter drill barrel cuts a clean hole through the centre of the ancient concrete. Once the core has been extracted the void is filled with inert sand, sealed with a pozzolanic mortar and capped with the original surface concrete that has been kept back from the sample collected.