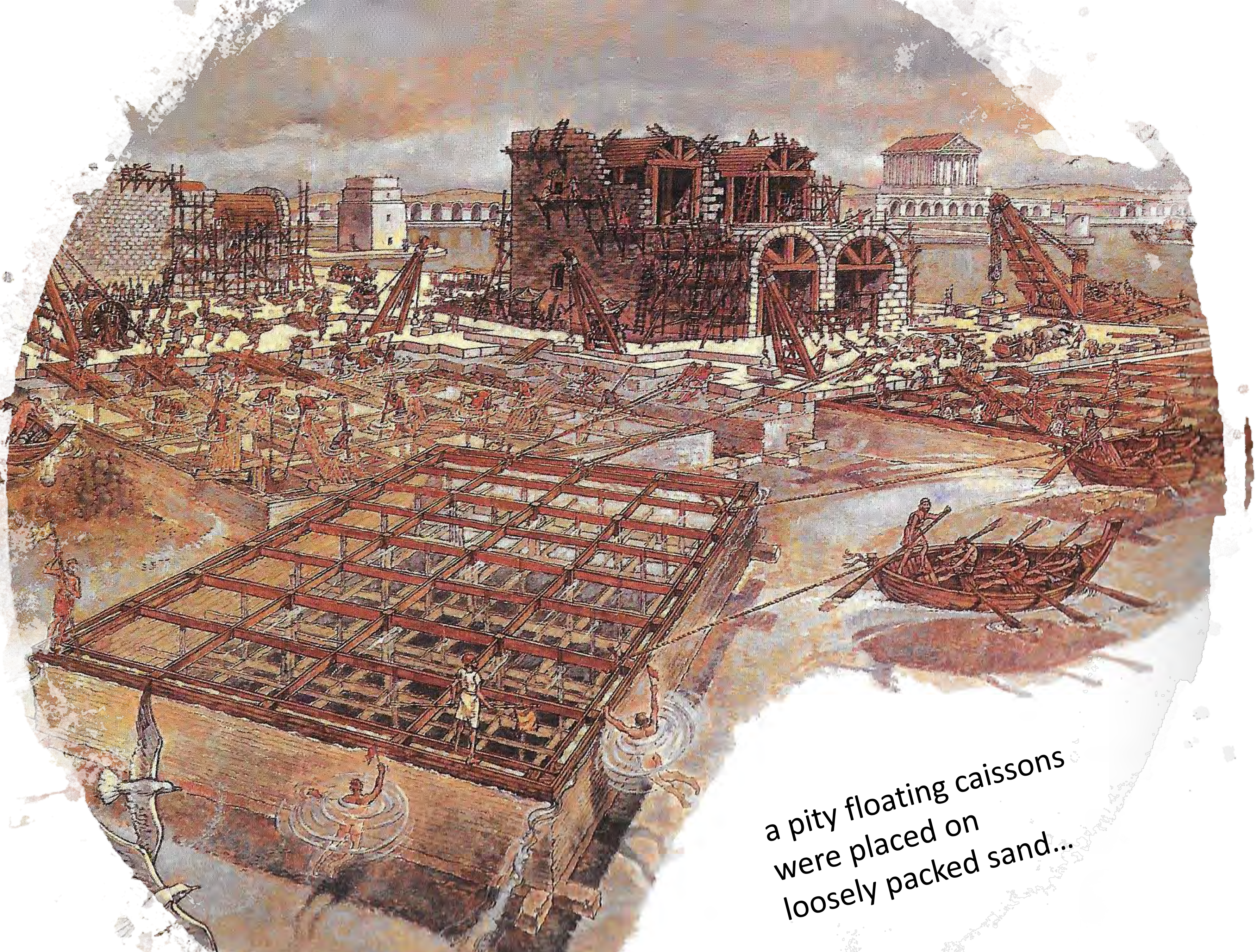
PALAEOPORTOLOGY

Ancient Coastal Settlements, Ports and Harbours

Coastal Engineering from another point of view...

Parallels between the ancient and the modern

What can we learn?



Teringo (1987)

Chronology of civilizations
Adapted from Inman (ICCE 1974)

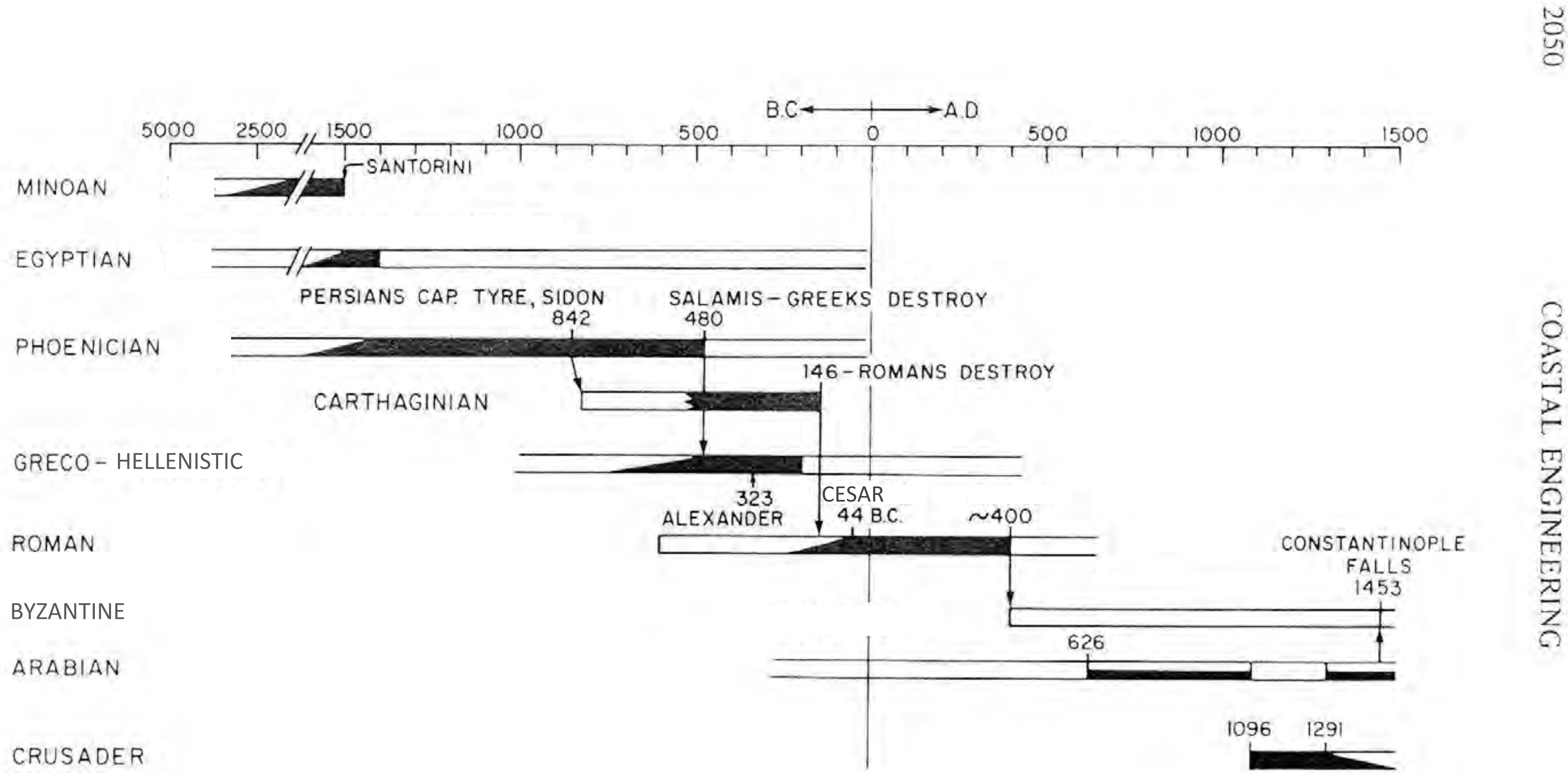
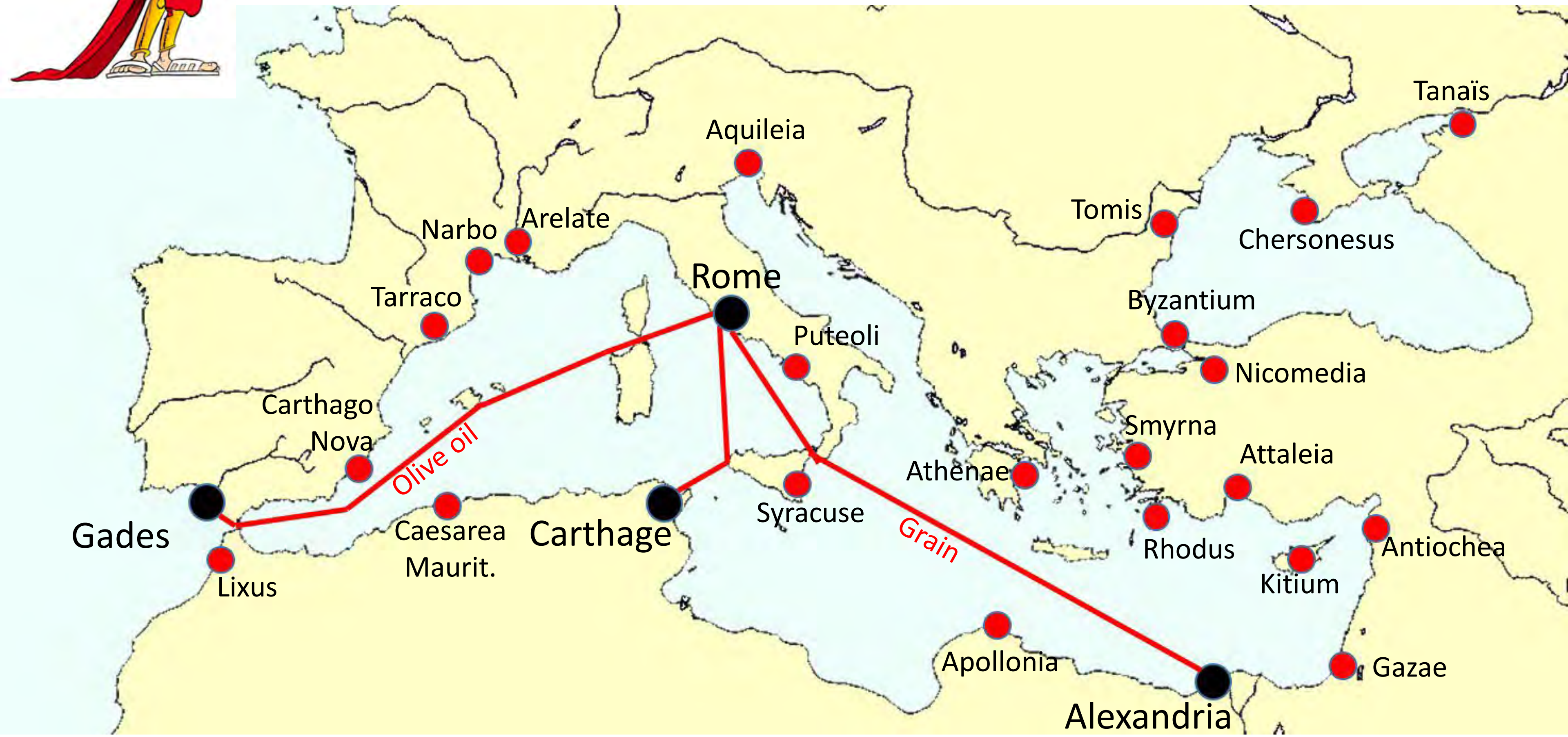
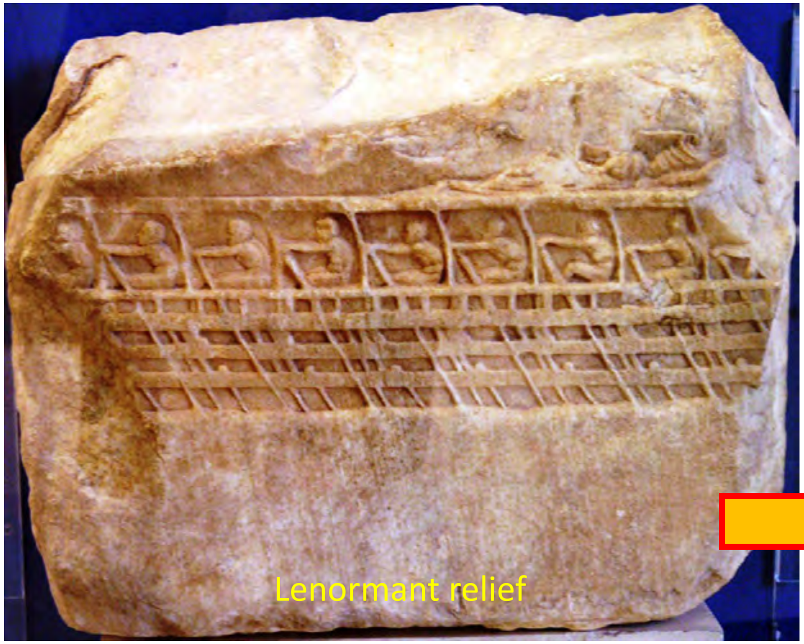


Figure 1. Chronology of civilizations' influence on Mediterranean harbors and ships.

MEDITERRANEAN TRADE in Roman times



Our knowledge is based on very limited information



CONTAINERS

Stowage of amphorae on board ancient ship
(Photo de Graauw, 2012, Antibes)

one amphora:

ca. 25 litres + 25 kg tare

large ancient ship (40 m):

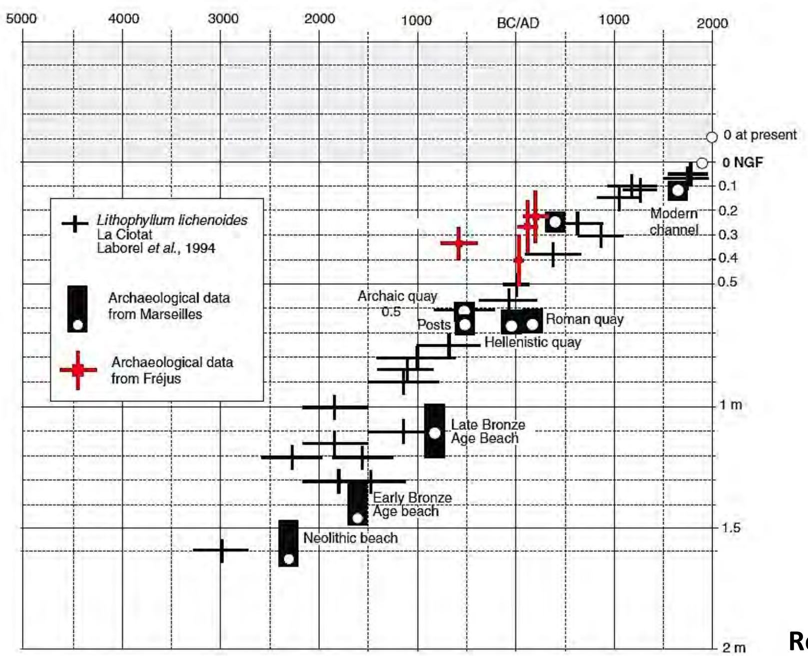
500 ton dwt (10 000 amphorae)

one TEU = nearly 500 amphorae (25 ton)

Wind: from observations made by Aristotle and Theoprastos, it is concluded that "**the winds of classical Antiquity were essentially the same as they are today**" (Murray, 1987).
Waves: same trend as wind.
Littoral drift: same trend as waves.

Hokusai (1830)

<u>Eustatic</u> **Sea Level Rise** was < 1 m in 2000 years.
Local crustal movements must be added to obtain a <u>Relative</u> Sea Level Rise.
This **R**SLR has been a discontinuous process (earthquakes).



Tsunamis: at least 400 earthquakes and/or tsunamis occurred in the Mediterranean area between 500 BC and 1500 AD,
i.e., up to **20 tsunamis/century,** mainly in the eastern Mediterranean Sea.

Relative SLR at Marseille, La Ciotat and Fréjus (Morhange, 2013)

Catalogue of Ancient Ports: **5900 places** (by 1/6/2024)

incl. **938** ports (**16%**) with *at least* one of the following structures:

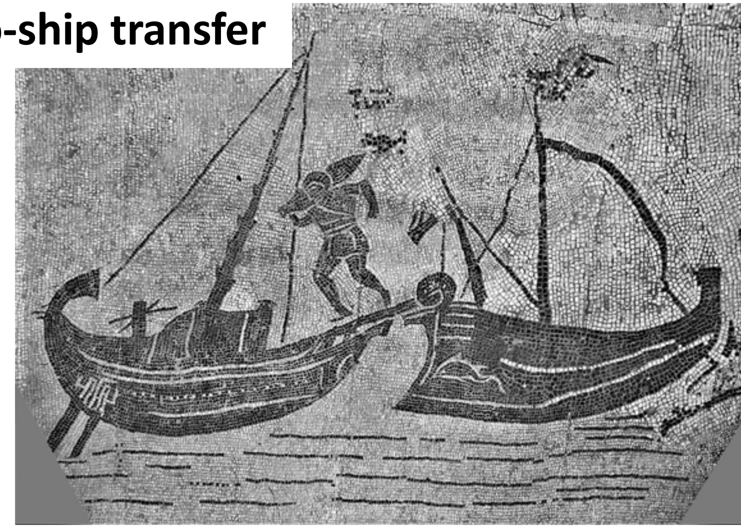
BW	Breakwater, usually called mole by archaeologists	385
QU	Quay (masonry with berthing on one side), pier or jetty (masonry with berthing on two sides), or landing stage (jetty on piles)	381
PL	Pila, large blocks made of marine concrete containing pozzolana	55
MO	Mooring device (bollard, pierced block)	85
CN	Canal (for navigation or basin flushing and/or desiltation)	74
SL	Slipway to take ships in/out of the water	140
SH	Shipshed (usually including a slipway)	87
SY	Shipyard (neoria, navalia) (incl. arsenals)	60
EX	Man-made basin excavated in the rock (e.g., Carthage's circular basin)	36
LK	Limen Kleistos, "closable" harbour with a narrow entrance	88
PH	Lighthouse	178
HO	Warehouse	98

Let’s review these structures briefly …

Beaching
possible on sandy beaches,
but not on silts (too flat)
or shingle-pebbles (too steep)

the most frequent way of landing cargo (ca. 85%)

Ship-to-ship transfer



Ship-to-ship transfer
(Mosaic at Piazza delle Corporazioni N° 25, Ostia).

Unloading wood by wadding labourers,
on 3rd c. mosaic found in Sousse.
(Photo de Graauw, 2018, Bardo Mus, Tunis)
(Votruba, 2017).

Unloading fish by wadding labourers in **Senegal**.
Picture by Franck Boyer (Kamikazz Photo agency, Dakar).

A vital need: fresh water…

Remains of timber jetty at **Yenikapi** (Istanbul).

Timber jetty on **Stabia** fresco detail (Pompei, 1st c.).

Port du Bec (**Vendée,** France)

Wooden jetties were preserved inside harbour basins,
but many jetties (now destroyed) must have existed on open coasts enabling deep-water access,
some stone jetties survived in Tunisia (Stone, 2016)

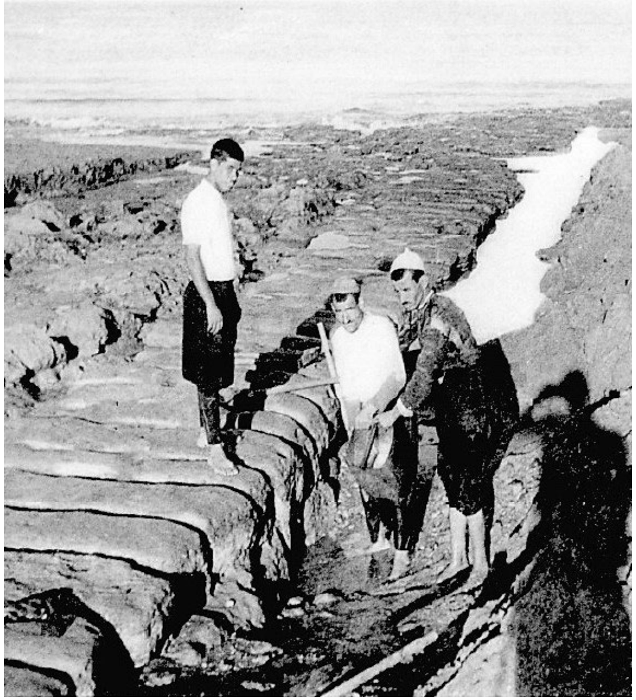
MOLES – BREAKWATERS « VERTICAL »

Archaic structures with ashlar

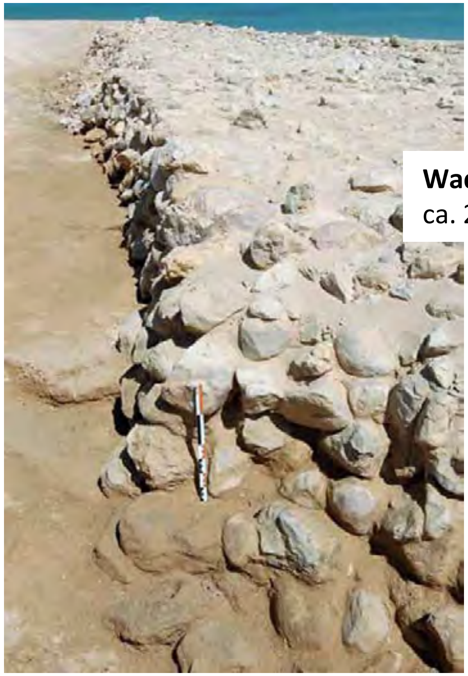
Tyre north mole (Lebanon) built with ashlar headers, 800 BC (Noureddine, 2010)

Also at **Athlit** (Israel), **Amathus** (Cyprus), etc.

Seleucia Pieria Roman south mole (Syria) built with ashlar headers, (Pamir, 2011)



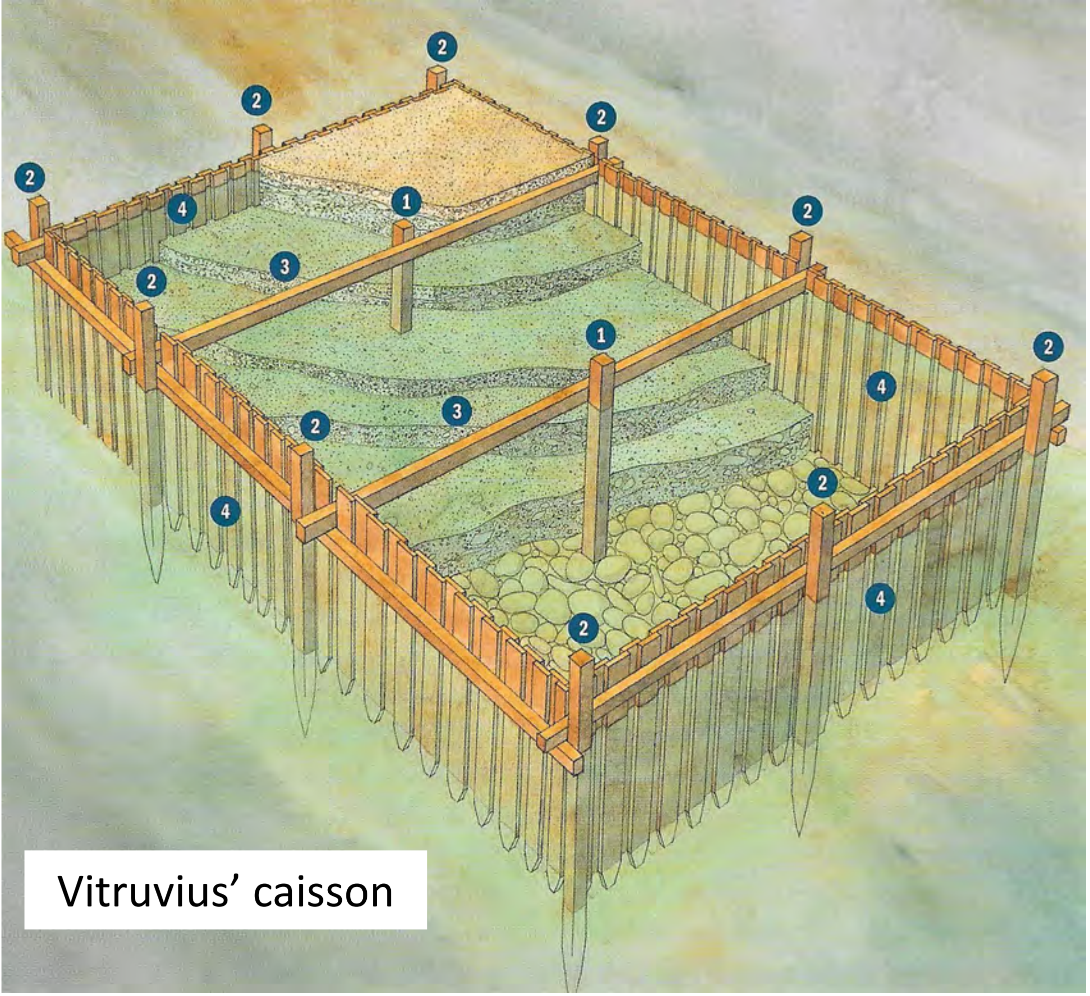
Tabbat el-Hammam mole (Syria) built with ashlar headers, 900 BC (Braidwood, 1940)



Wadi al-Jarf (Egypt) ca. 2750 BC, (Tallet, 2015)

MOLES – BREAKWATERS « VERTICAL »

Roman structures with concrete



Caisson built out from the shore (Golvin, 2020 & Oleson, 2014)

1: central poles

2: lateral poles (stipites)

3: tie beams (catenae)

4: wooden walls

Roman concrete has a surprising longevity, incl. in marine conditions.
This is not only due to pozzolanic effect, but also to a self-healing effect due to long term preservation of lime clasts inside the initial mortar (Seymour, 2023)

Portus' north **concrete breakwater** showing imprints of transverse caisson beams (Photo de Graauw, 2011)

Pilae at **Portus Iulius** (Italy)
(Google Earth, 2007).

Around 50 places with pilae
three are proven arched breakwaters
but only *one* is still visible

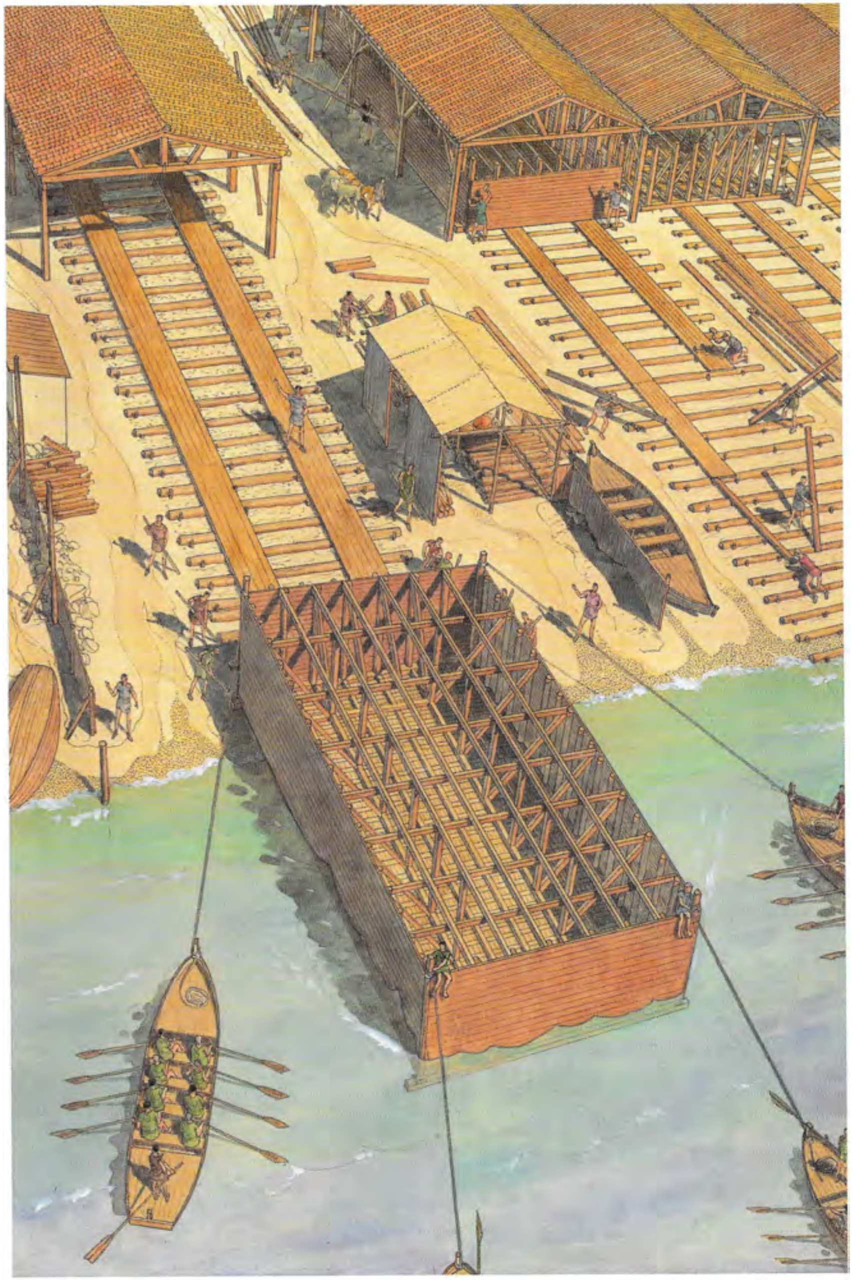
Arched breakwaters at the isle of **Nisida** (Italy),
by Bartolomeo Picchiatti (1635) (looking southward)

Puteoli breakwater on **Stabia** fresco detail (Pompei, 1st c.)

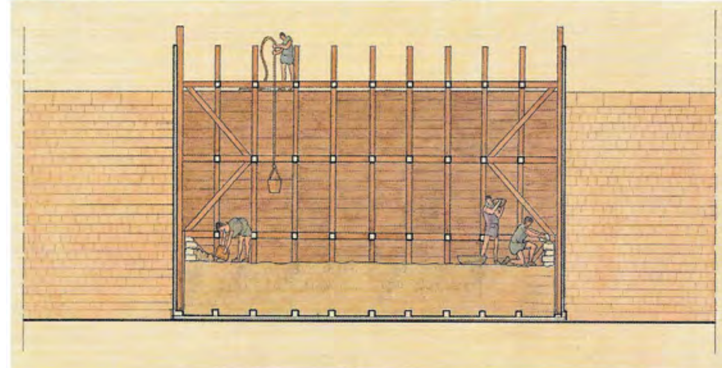
Visit Civitavecchia Wednesday!

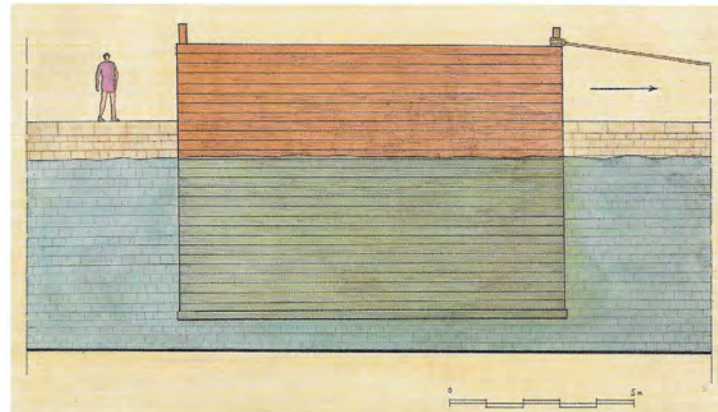
Molo del Lazzaretto at **Civitavecchia** (Italy), (Photo de Graauw, 2022)

PILAE



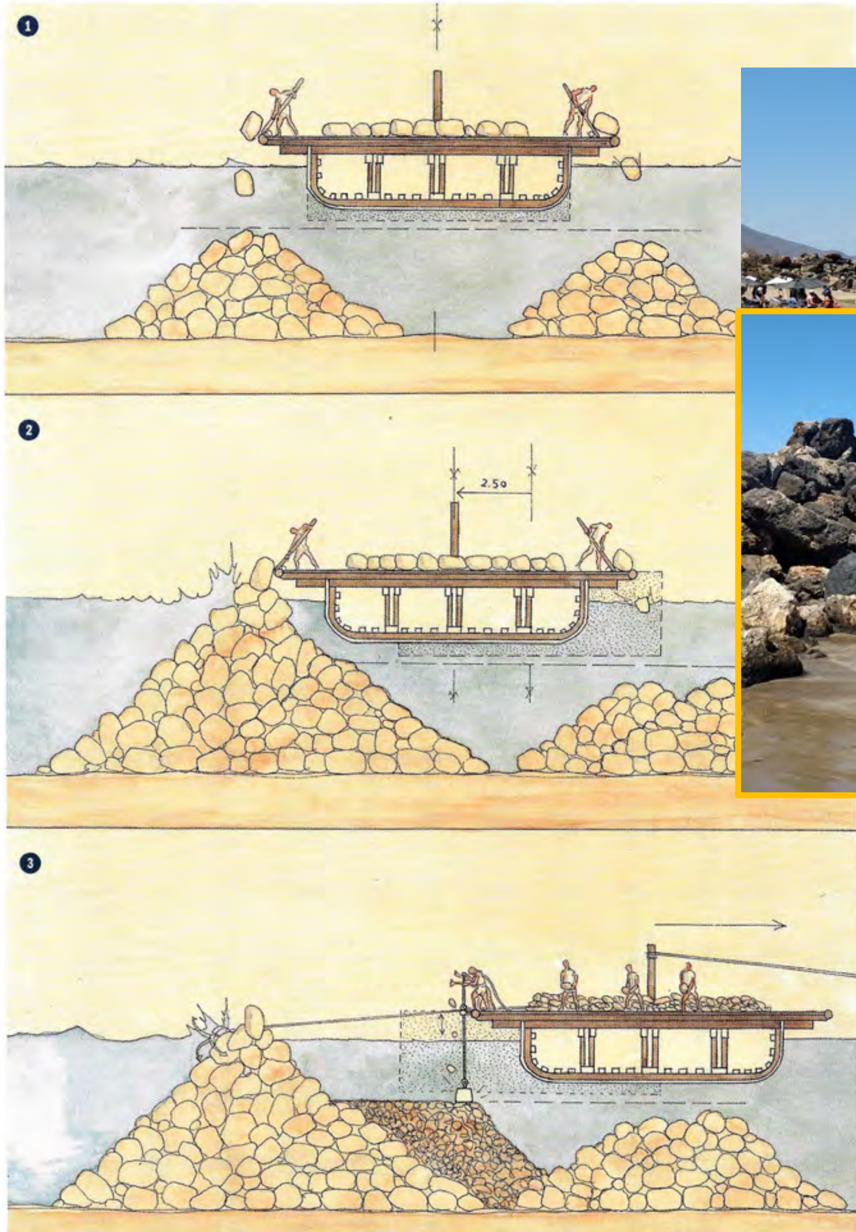
Launching a floating caisson from a slipway (left) or from a drydock (right) (Golvin, 2020)





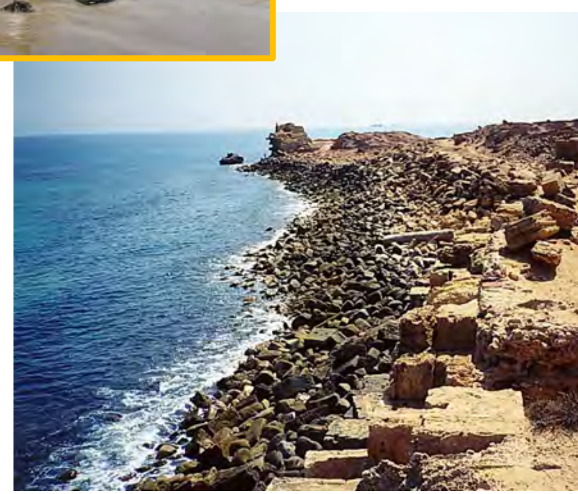
Pilae remains at Scidrus, near Sapri (Photo Franco, 2008)

MOLES – BREAKWATERS « SLOPING » rubble mounds

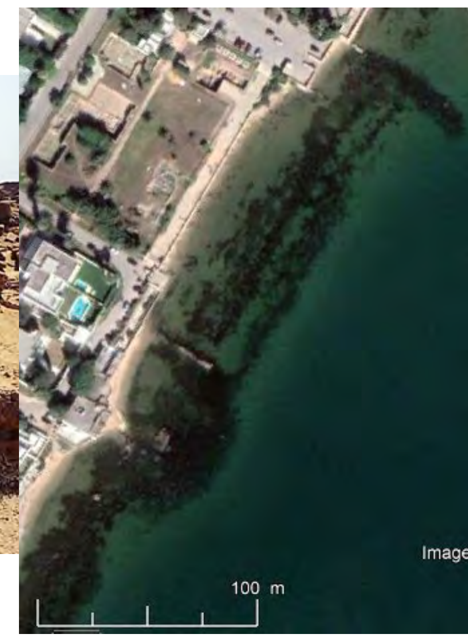


Construction of a rubble-mound breakwater
(Golvin, 2020)

Rubble-mound breakwater at **Kissamos** (Crete)
(Photo de Graauw, 2022)



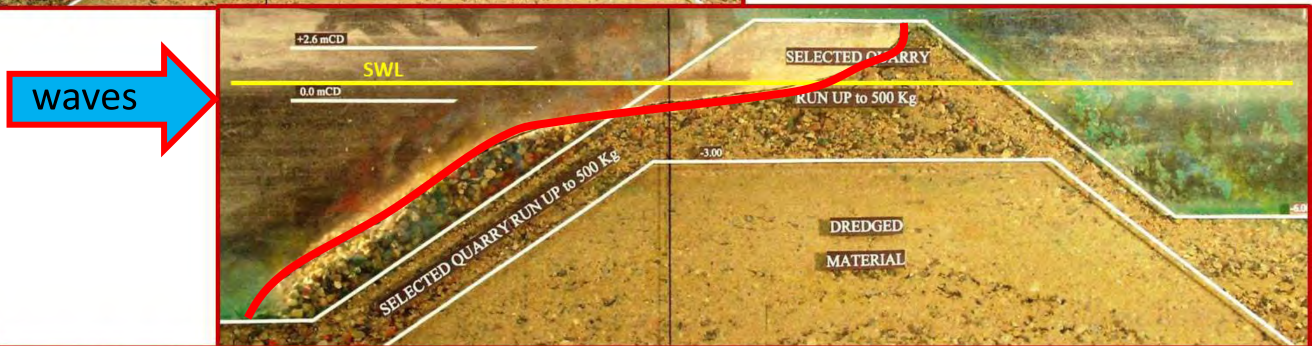
Berm breakwater at **Leptis Magna**
(Photo de Graauw, 2001)



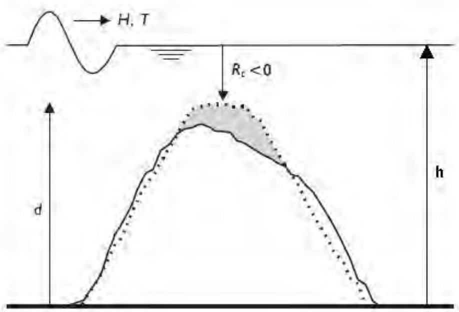
Double-line rubble-mound breakwaters at Carthage,
also at Paphos, Caesarea Maritima

MOLES – BREAKWATERS « SLOPING » rubble mounds

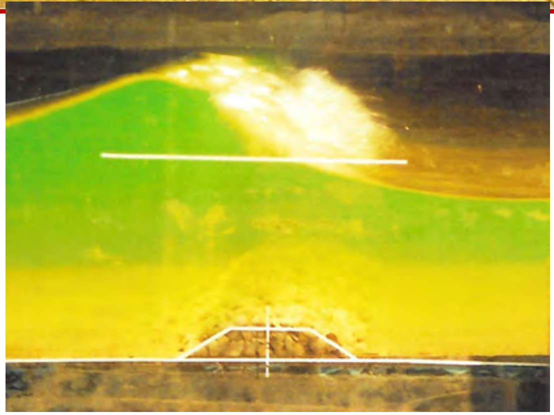
Scale model tests on overtopped structure

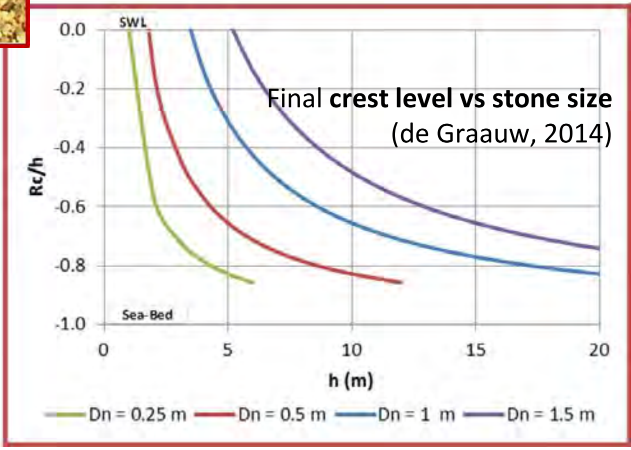


Two phases:
1: erosion of front crest
2: crest erosion towards rear slope



Failure of rubble mounds in the long term
(i.e., assuming breaking waves)





Timber quay wall of place Jules Verne, **Marseille** (France), (Inrap 1993)

Roman quay wall at **Marseille** (France) built with ashlar stretchers (Inrap, 2006)

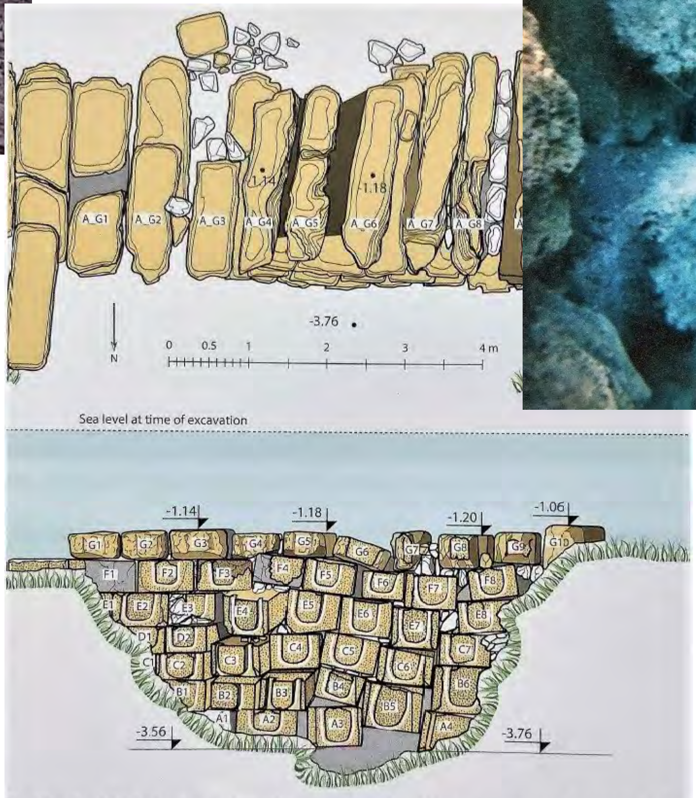
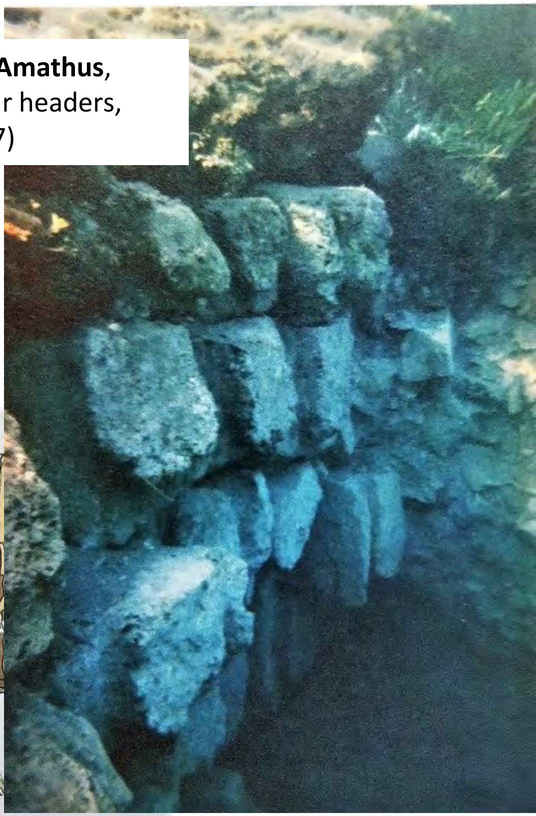
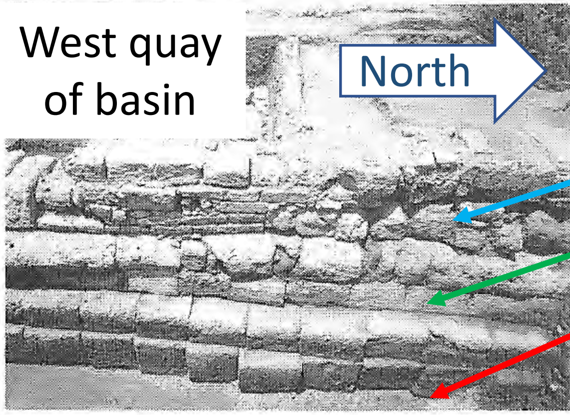


Fig. 12 — South Mole, Sondage A, plan and section with numbered blocks (drawing and CAD EFA, T. Koželj)



Hellenistic quay wall at **Amathus**, (Cyprus) built with ashlar headers, 300 BC (Empereur, 2017)

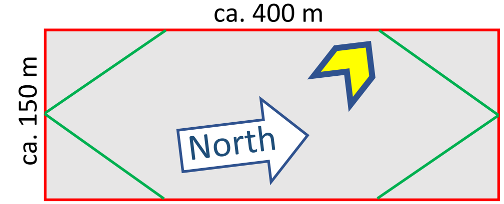
West quay of basin



Byzantine

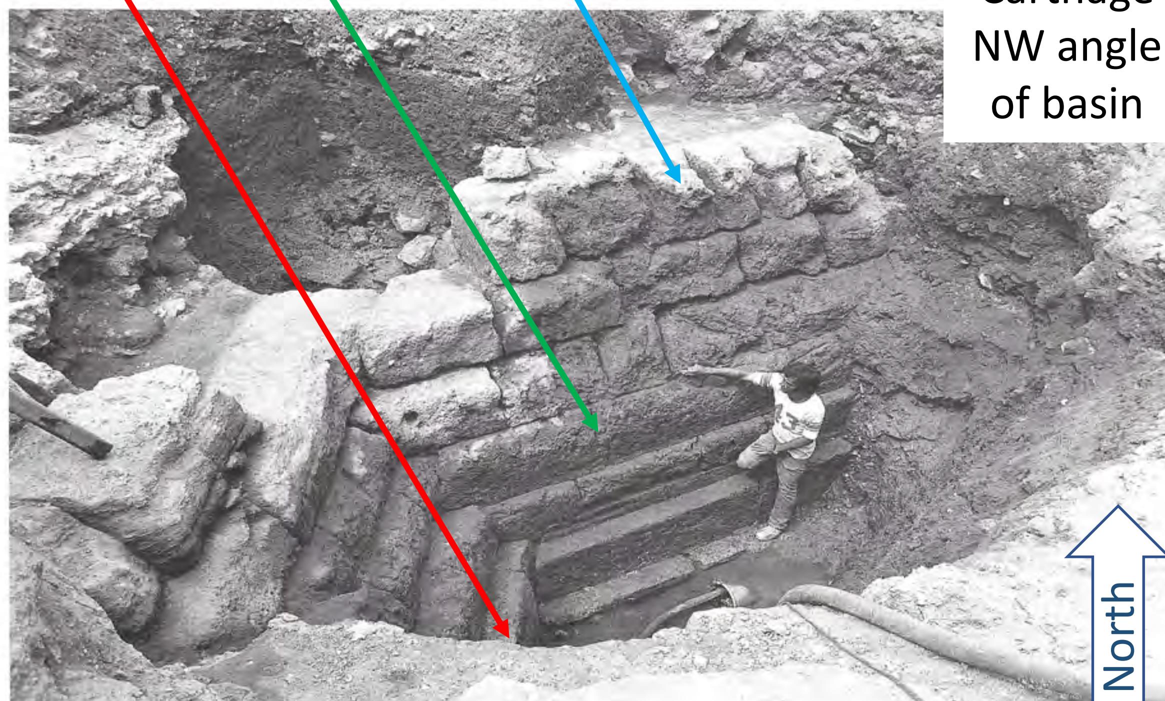
Roman

Punic



Le mur du quai occidental du port commercial de l'époque punique avec les reconstructions plus récentes des époques romaine et byzantine. Les deux ou trois assises les plus basses des blocs de grès massif datent de la période punique tardive (IIIe-IIe siècle avant J.-C.). Les assises supérieures de pierres plus petites indiquent les reconstructions plus récentes des périodes romaine (peut-être IVe siècle après J.-C.) et byzantine (peut-être début du VIe siècle après J.-C.)

Carthage NW angle of basin

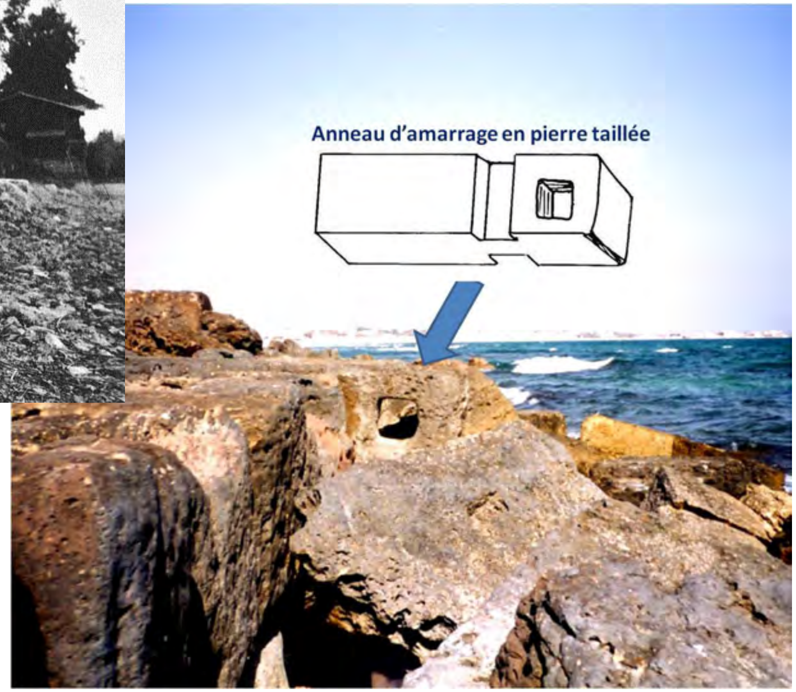


Le coin nord-ouest du port commercial romain (vu du sud). Cet angle oblique a été ajouté au début du IIe siècle après J.-C., afin de transformer le port rectangulaire de la période punique tardive et de lui donner une forme d'hexagone allongé. A gauche, on aperçoit le mur punique tardif, qui continuait à l'origine tout droit vers le nord, rejoignant la partie romaine ajoutée

Source: Ennabli, 1992

MOORINGS

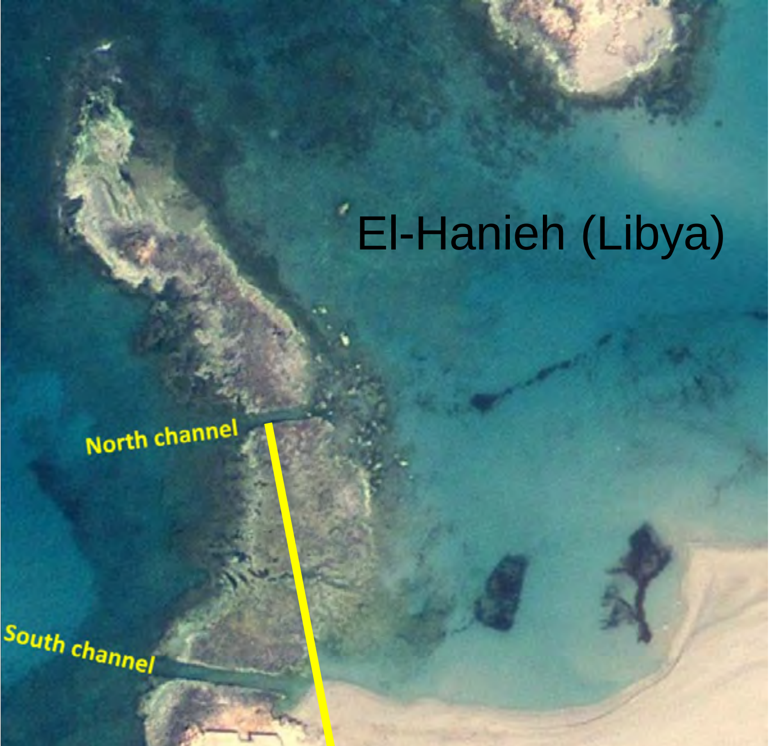
Mooring ring at **Portus Trajanus** (Italy)
(Testaguzza, 1970, p 170)

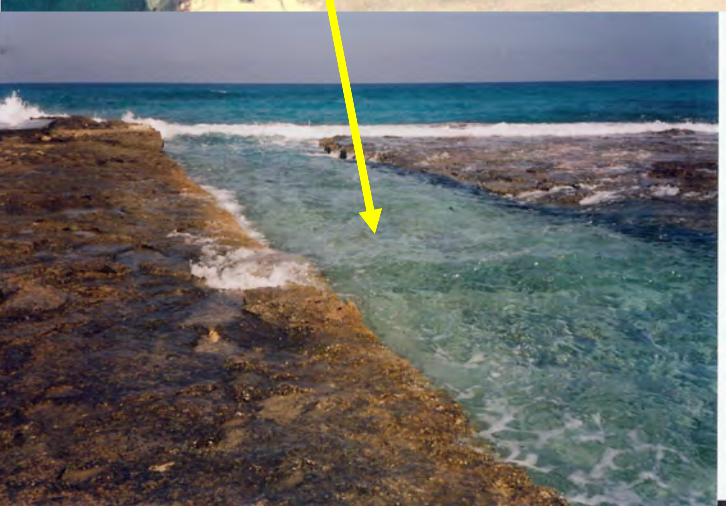


Leptis Magna (Libya) (photos de Graauw, 2000)

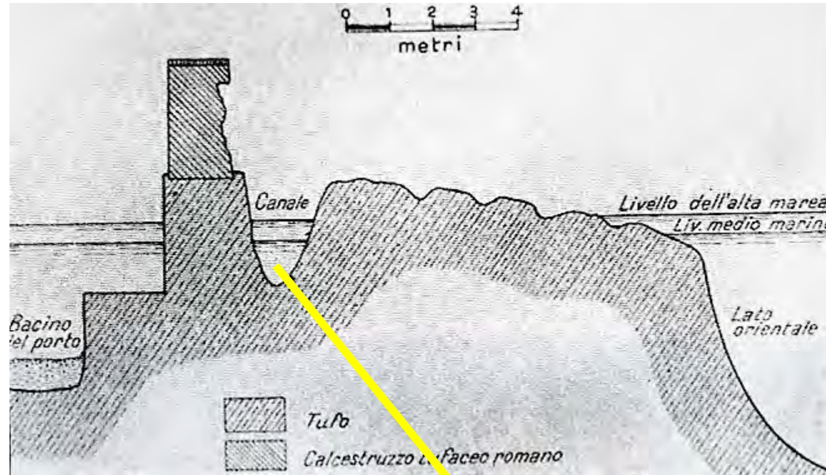
Possible foot-hole of a derrick mast
at **Aquileia** (Italy), (Photo de Graauw, 2010)

FLUSHING CANALS





El-Hanieh (Libya) northern flushing channel
(Photo Misson, 5/10/2010)



Ventotene (Italy) canal in front of breakwater

Ansedonia (Italy) Tagliata Etrusca
(Photo Paolo Della Capanna)

Carthage (Tunisia)
(photo A. de Graauw, 2018).

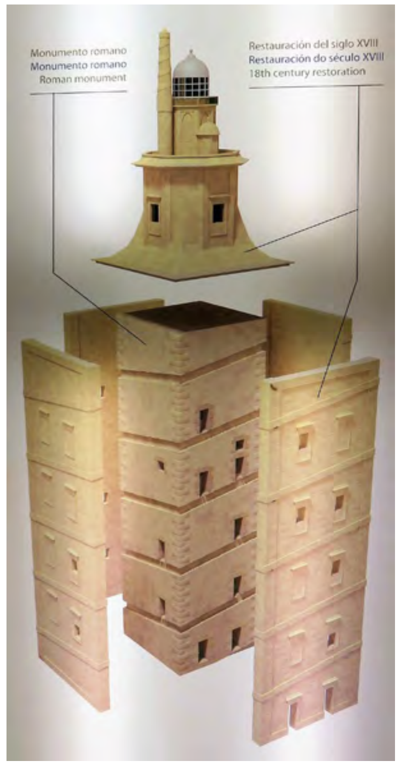
Zea (Piraeus, Greece)
(photo de Graauw, 2013).

BLACKMAN, D. & RANKOV, B. et al. (2013)
“Shipsheds of the Ancient Mediterranean”,
Cambridge University Press, (617 p).

LIGHTHOUSES & WAREHOUSES

Leptis Magna (Libya)
(photo de Graauw, 2000).

Farum Brigantum
A Coruna (Spain)



Visit Portus or Ostia Wednesday!

Portus (Rome, Italy)
(photo de Graauw, 2022).

TRETHEWEY, K. (2018) “Ancient Lighthouses, and other lighted aids to navigation”, Jazz-Fusion Books, Cornwall, UK.

CHANKOWSKI, V., et al. (2018) “Entrepôts et circuits de distribution en Méditerranée antique”, École française d’Athènes.

PORTUS
Largest Roman port

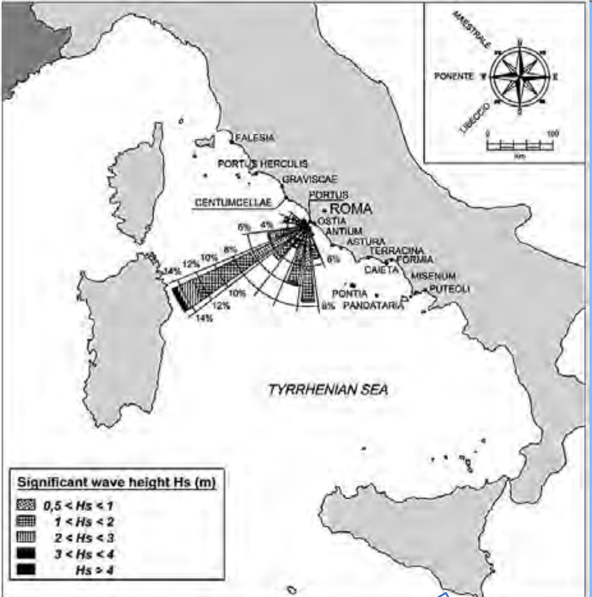
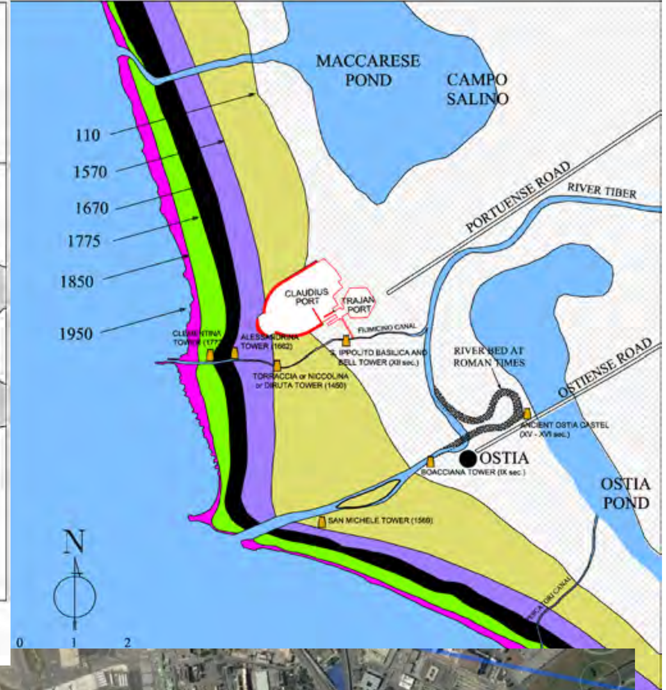
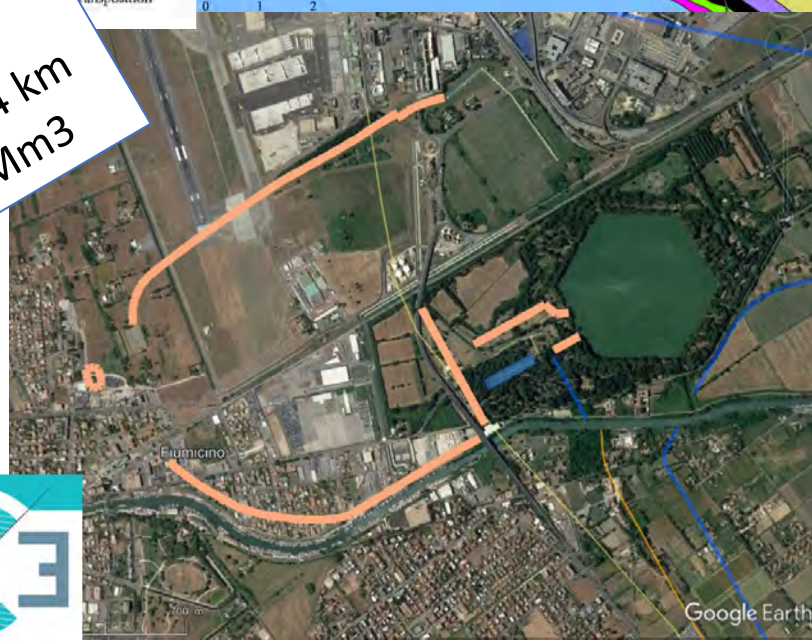
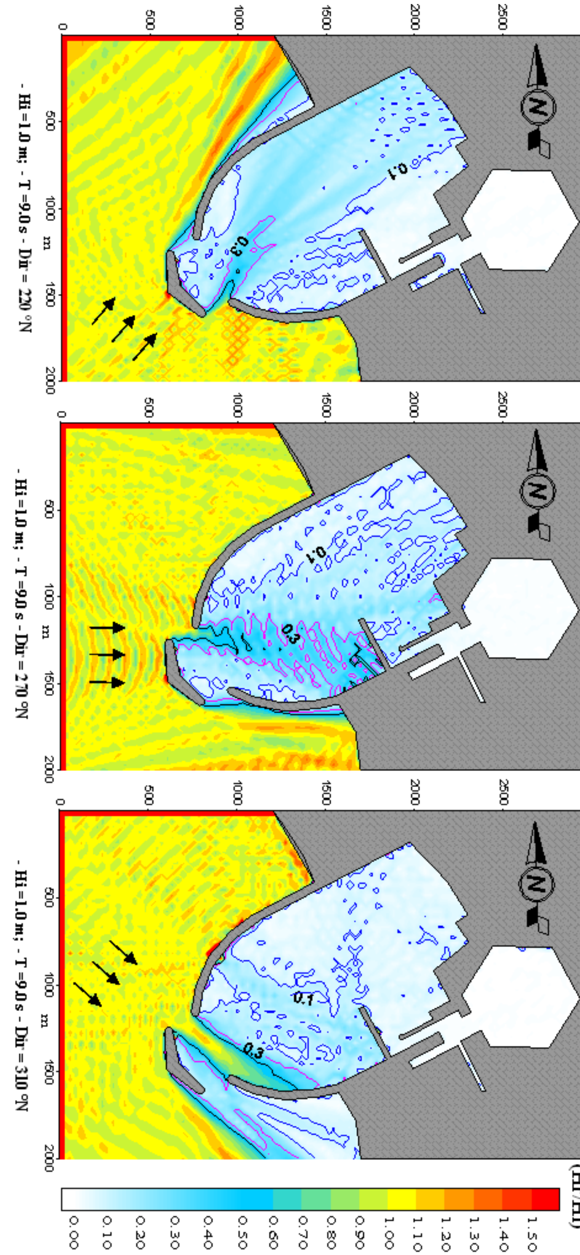


FIG. 2. Geographical map with location of main ancient ... near Rome and representation of the directional wave climate offs... ransposition of Ponza buoy records ...



Basin: 200 ha
Breakwaters: ca. 4 km
Dredging: 4-5 Mm3





NOLI, A., & FRANCO, L., 2009, "The ancient ports of Rome: new insights from engineers", Archaeologia Maritima Mediterranea, 6, (p 189-207).

Carthage's circular basin:
ca. 0.15 Mm^3
(5 ha x 3 m)

Portus Trajanus: ca. 2 Mm^3
(33 ha x 7 m)

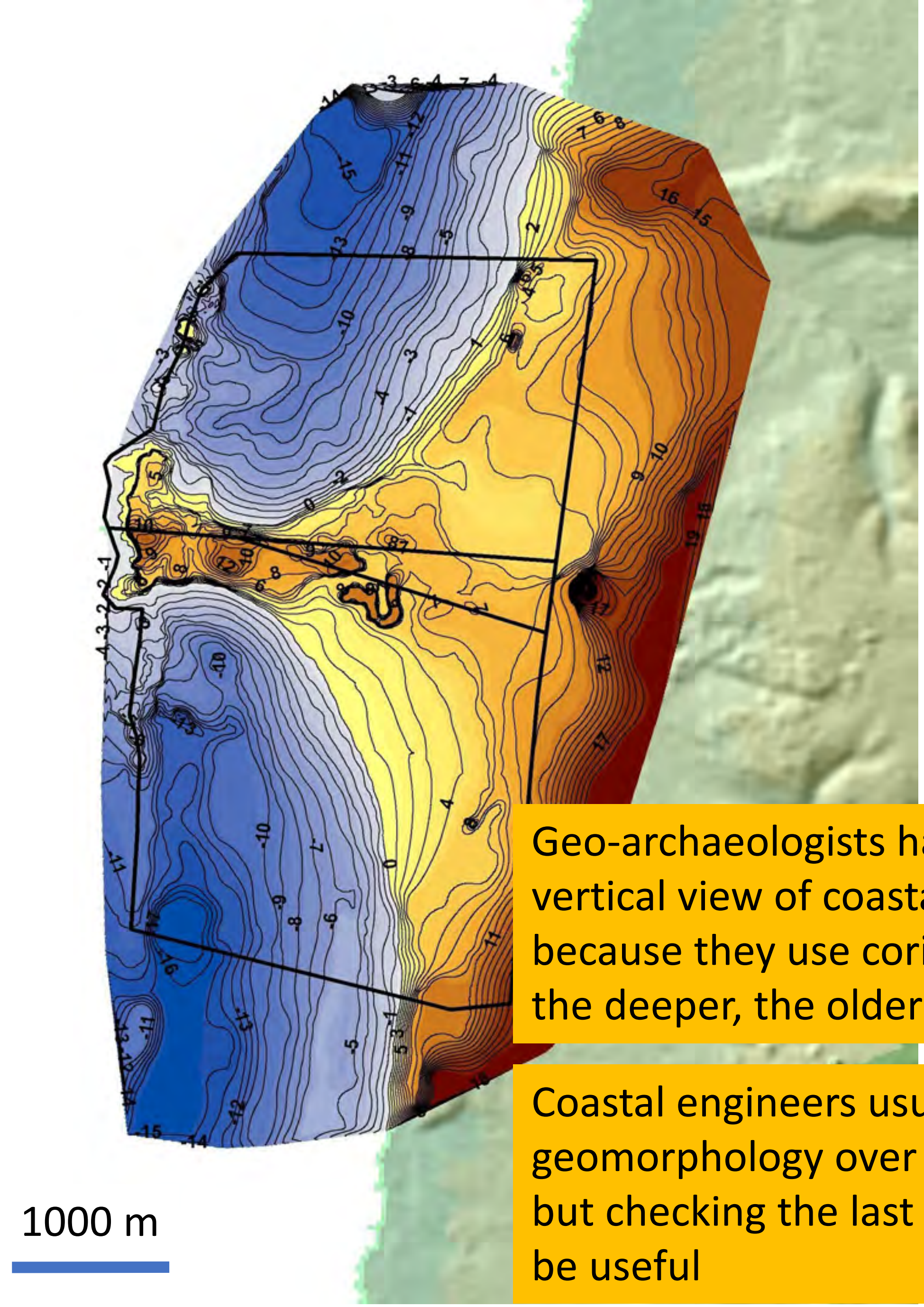
CARAYON, N., et al., 2017, "Kothon, cothon et ports creusés", MEFRA, 129/1, (p 255-266).

ACCRETION at TYRE

''initial'' layout

Layout at Alexander's arrival 332 BC. + 10 Mm^3

Modern layout + 30 Mm^3 with 30-50 000 m^3/year >> 6 to 10 centuries



Geo-archaeologists have a vertical view of coastal morphology, because they use corings: the deeper, the older

Coastal engineers usually oversee geomorphology over < 100 years, but checking the last 1000 years may be useful

SUBMERGENCE
up to 5-6 m

Coastal sites **submerged** by more than 1 m in the last 2000 years:
>> Aegean Sea
>> Western Italy
>> Nile & Rhône deltas

Ancient harbour structures were often built directly on loosely packed sand provided by longshore sediment transport

>> Liquefaction affecting cohesionless water-saturated sand
>> Wave-induced compaction
+ Tectonic activity & Glacial Isostatic Adjustment

Aelius Aristides witnessed the 178 AD earthquake in Smyrna (Turkey):
"some of the temples have **fallen**, some **sunk** beneath the ground"

Most ancient shelters had no port structures at all (ca. 85%):
a sheltered sandy beach sufficed.

The oldest breakwaters and quays were made of:
Masonry on shallow waters (h < 2 to 3 m + exceptions)
rubble mounds on deeper waters
Roman quays and breakwaters used marine concrete poured into wooden caissons.

Harbour siltation has always been a problem:
structural solutions have not been very efficient (arches, flushing canals)
dredging is the only way… before abandon the place (ca. 10-15%)
checking the long-term geomorphology is often useful

Subsidence has sometimes been a problem:
Liquefaction affecting cohesionless water-saturated sand
Compaction due to wave-loads on vertical structures

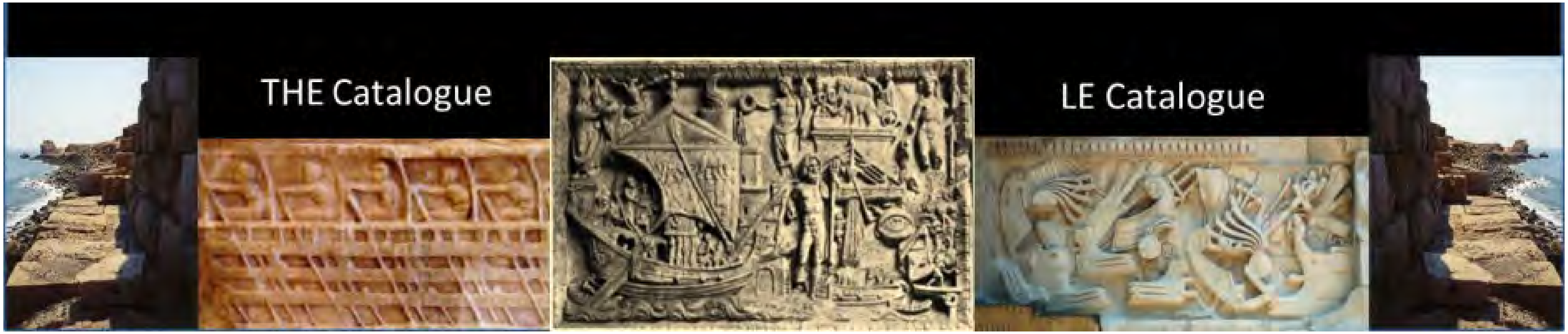
Many tsunamis occurred in the Med area

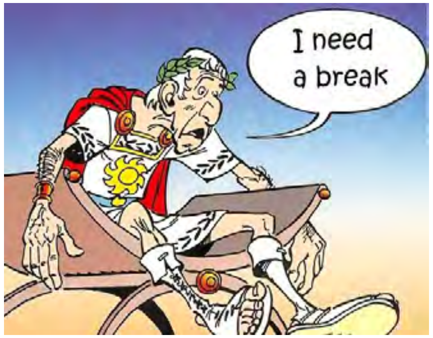
Today's technology comes from our ancestors up to 5000 years ago,
sometimes nearly lost and reinvented (use of pozzolana).

Please respect ancient cultural heritage when implementing new infrastructures,
as we can still learn from them…

Thank you for your attention

www.AncientPortsAntiques.com





DE GRAAUW, A., (2022), "Ancient Port Structures, Parallels between the ancient and the modern", https://journals.openedition.org/mediterranee/12715

PILAE

Construction of a breakwater with pilae and arches
(Golvin, 2020)

Pilae remains at Scidrus, near Sapri
(Photo Franco, 2008)

Roman structures with concrete

Large masses of concrete are useful for massive structures like ramparts and thick walls, towers, harbour breakwaters, the like. However, unreinforced concrete cannot withstand tensile forces such as those generated by flexion.

17th c. arch of the Ermita de Santa Barbara at Alicante (Spain)
(Photo de Graauw, 2015)

Reason why arches were used until reinforced concrete was invented at the end of the 19th c.

Courses of bonding tiles in the London Wall

Reason why courses of bonding tiles were included into massive walls and ramparts.