

Remains of ancient breakwaters

Rubble-mound breakwaters consist of piles of stones more or less sorted according to their unit weight: smaller stones for the core and larger stones as an armour layer protecting the core from wave attack.



Ancient rubble mound breakwater at Kissamos (Crete) (pict. H. Hampsa, 2006).

This is possibly the only large rubble mound breakwater that is above the sea today as it was uplifted by 6 meters during the 365 AD earthquake and therefore protected from further wave attack. It can be seen that the armour layer consists of ca. 1 m rock boulders, or around 1 to 1.5 ton. It would be interesting to check if this structure includes a core with finer material located underneath the armour layer, or if the whole structure was made of the 1 m rock still visible at its surface.

This kind of structure has been around for over 2500 years and modern coastal engineers still build them to create harbours sheltered from wave penetration. It was widely used for breakwaters in water deeper than a few meters where positioning of ashlar headers by divers was difficult. Ancient breakwaters may have been over- or undersized and the result is that only a few breakwaters have been luckily preserved, while many others are now found under water as “submerged breakwaters”, as a consequence of 2000 years of storms.

Without going into the details of breakwater design, it can be understood easily that stability of a structure made of stones depends primarily on the stone size in relation to the strength of wave action: breakwaters in open waters exposed to storms acting on large areas and therefore inducing high waves, must consist of larger stones than breakwaters located in sheltered areas.

A study was carried out to find some simple relation between the governing parameters (water depth, structure height, stone size) and the equilibrium position of the crest of rubble mound breakwaters subject to long term wave attack in breaking wave conditions (see section on “Failure of rubble mound breakwaters in the long term”, hereafter).

It was concluded that undersized emerging rubble mound breakwaters reduce to submerged breakwaters and that, for a given stone size, submerged breakwaters stabilise to a predictable crest level after long term wave attack in breaking wave conditions.

For ancient breakwaters, this means that:

- We may find a few ancient breakwaters still in perfect condition: they were emerging and fulfilling modern design conditions (they were somewhat oversized!);
- If slightly undersized, we may find ancient breakwater that were reshaped into an S-shape by 2000 years of storms: the seaward side is lowered to below Sea Water Level (SWL) and the landward side may reach SWL (see section on “Sea Level Rise”);
- If more undersized, ancient breakwater will be lowered by wave action to a level depending on the stone size.

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We must also remember that the SWL rose about 0.5 m since antiquity, so that breakwaters that were stable at that time in shallow water (a few meters water depth) may not be stable anymore because larger waves can reach them nowadays.

In tidal areas, the worst conditions for stability occur when the largest waves occur together with the highest water level. The probability of occurrence of this happening is smaller than for a fixed water level, but that may not change the final result for stability in the long term.

Careful examination of historical Google Earth images enables us to see quite a few breakwaters in shallow waters. A collection of such images is given in Appendix 2, together with some other pictures made on site.

Some remarkable ancient rubble mound breakwaters can be listed as follows:

- Portus (Fiumicino, Italy): deepest section of the 3200 m long breakwaters, now inland;
- Pharos (Alexandria, Egypt): over 2300 m long, submerged in open water;
- Thapsus (Bekalta, Tunisia): about 870 m long, submerged in open water;
- Paphos (Kato Paphos, Cyprus): about 600 m long, with a parallel one 200 m long, submerged in open water;
- Leptis Minor (Lamta, Tunisia): about 560 m long pier, submerged in open water;
- Leukas/Ligia (Lefkada island, Greece): about 540 m long, submerged in sheltered water;
- Pythagoreion (Samos island, Greece): about 480 m long, submerged in open water;
- Acholla (Ras Boutria, Tunisia): about 460 m long pier, submerged in open water;
- Chersonesos (Cape Agami, Egypt): about 400 m long, submerged in open water;
- Sullethum (Salakta, Tunisia): about 350 m long, submerged in open water;
- Tieion (Filyos, Turkey): over 350 m long, submerged in open water;
- Mytilini (Lesbos island, Greece): about 350 m long, submerged in sheltered water;
- Sabratha (Libya): about 320 m long, submerged in open water;
- Leptis Magna (Lebda, Libya): about 300 m long, berm breakwater in open water;
- Methone (Modon, Greece): about 250 m long, submerged in fairly open water;
- Neftina (Lemnos island, Greece): about 200 m long, submerged in open water;

and many others, smaller ones.

Obviously, questions remain on many of these structures, e.g. is the structure at Emporia (Spain) a breakwater or a city wall falling into the sea? Was the Thapsus (Tunisia) structure a rubble mound breakwater or a vertical breakwater? Is the Kainopolis (Libya) feature a breakwater or just some beach rock? etc. etc.

An index of all breakwaters collected here is given hereafter (see pictures below).

Everybody is welcome to send me more information and pictures on ancient breakwater remains ...

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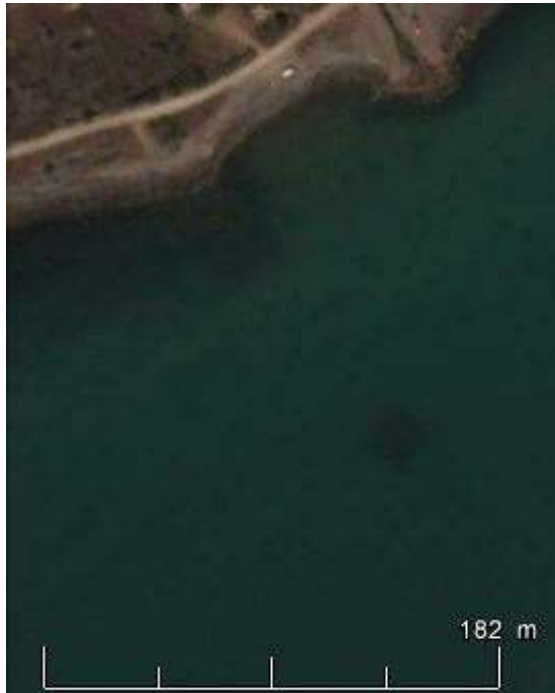
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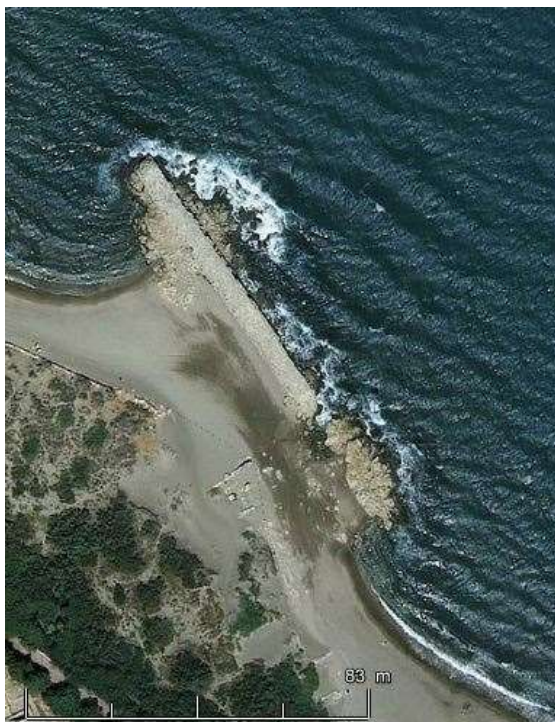
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Remains of submerged breakwaters on Google Earth



Saguntum, GE 2011 (Grao Vell at Sagunto, Spain)



Emporia city wall, GE 2009 (Sant Marti d'Empuries, Spain)

Remains of ancient breakwaters



Emporia city wall, de Graauw 2008 (Sant Marti d'Empuries, Spain)



Maritima Civitas Colonia, GE 2003 (Les Laurons, France)

Remains of ancient breakwaters



Nora, GE 2013 (Capo di Pula, Sardinia)



Pisa, GE 2012 (Pisa-San Rossore, Italy)

Remains of ancient breakwaters



Portus Domitianus, GE 2013 (Santa Liberata, Italy)



Pyrgi, GE 2006 (Santa Severa, Italy)

Remains of ancient breakwaters



Portus, GE 2007 (Fiumicino, Italy)



Portus, de Graauw 2011 (Fiumicino, Italy)

Remains of ancient breakwaters



Antium, GE 2010 (Anzio, Italy)

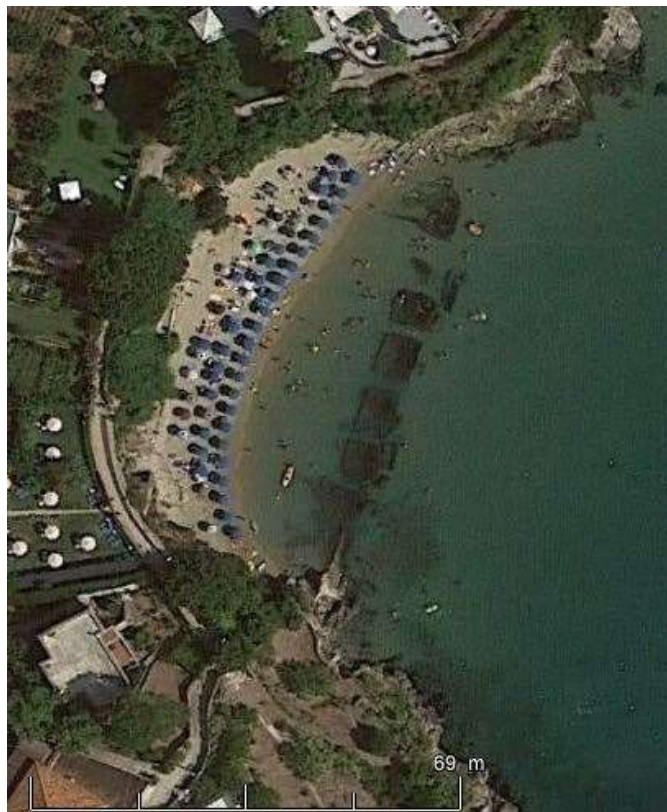


Astura, GE 2016 (Torre Astura, Italy)

Remains of ancient breakwaters



Circei, GE 2014 (Cape Circeo, Italy)



Caieta, GE 2013 (Spiaggia di Fontania, at Gaeta, Italy)

Remains of ancient breakwaters



Nesis, GE 2007 (Nisida, Italy)



San Marco di Castellabate, GE 2007 (Italy)

Remains of ancient breakwaters

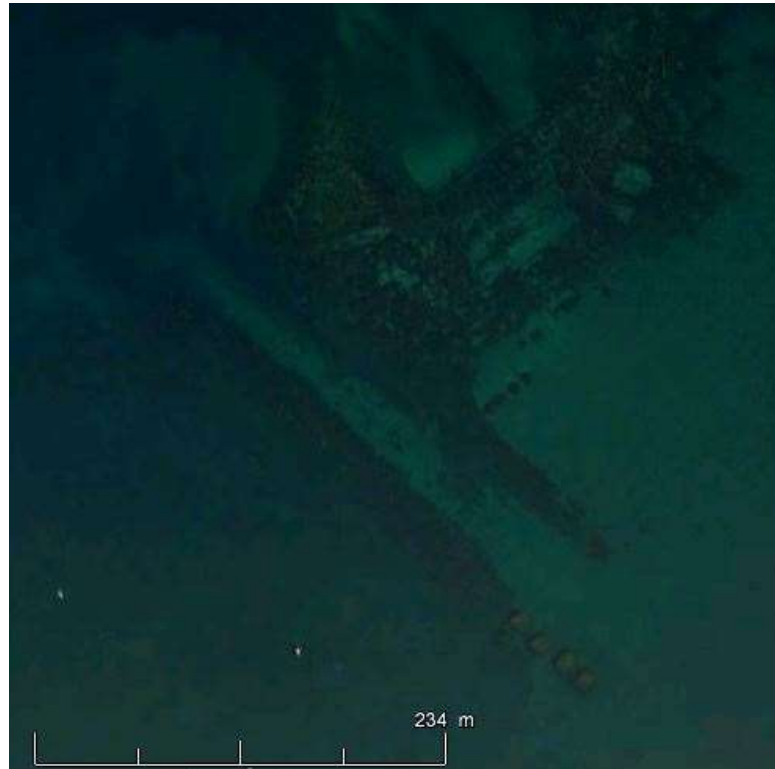


Misenum, GE 2007 (Miseno, Italy)



Baiae, GE 2007 (Baia, Italy)

Remains of ancient breakwaters



Portus Julius, GE 2007 (Lucrino, Italy)



Puteoli, GE 2017 (Pozzuoli, Italy)

Remains of ancient breakwaters



Megara Hyblaea, GE 2007 (Banchinamento Orsi, in Augusta harbour, Sicily)



Kossura, GE 2012 (Pantelleria, Italy)

Remains of ancient breakwaters



Ramla Beach, GE 2017 (Gozo, Malta)



Silvium, GE 2013 (Savudrija, Istria, Croatia)

Remains of ancient breakwaters



Pullaria, GE 2007 (Brioni island, Croatia)

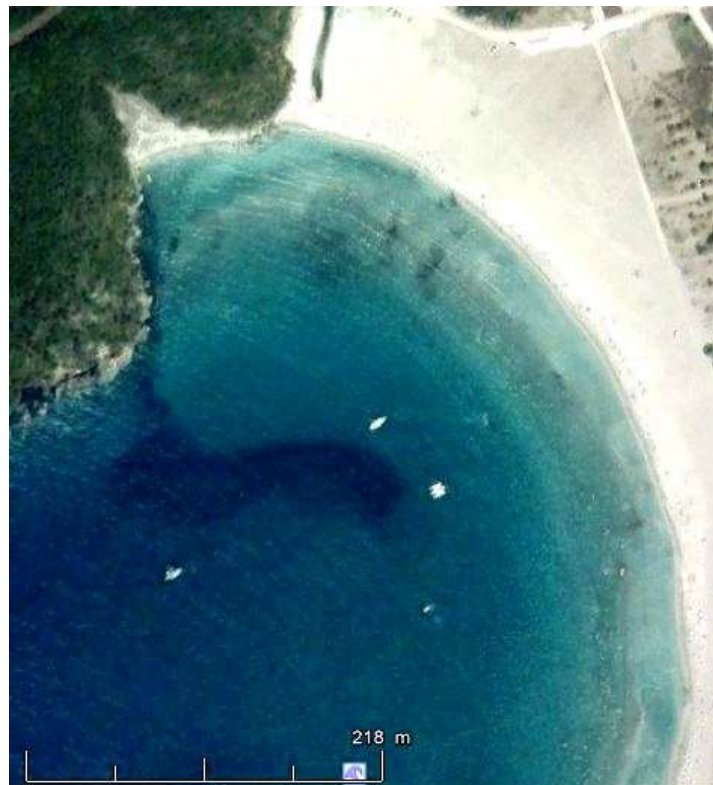


Leukas, GE 2012 (Lefkas island, Greece)

Remains of ancient breakwaters

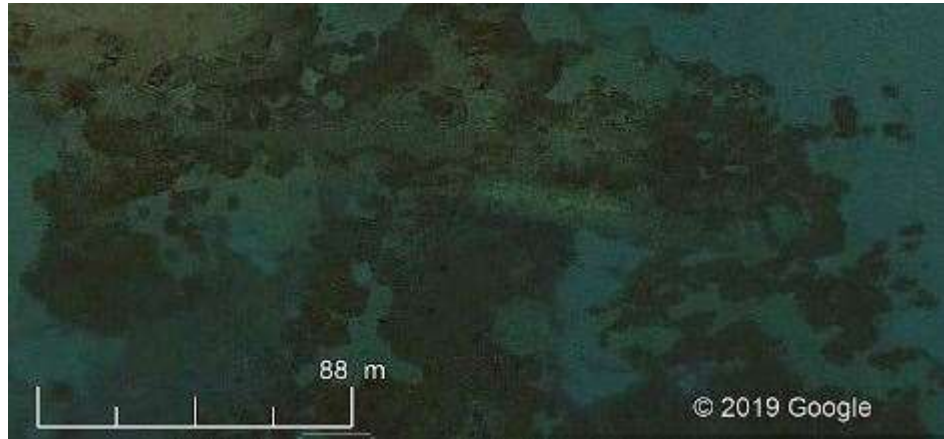


Sami, de Graauw 2013 (Kefalonia island, Greece)



Cheimerion, GE 2006 (Amoudia, Greece)

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Pogonia, GE 2017 (Palairos, Greece)



Salamis, GE 2008 (Salamine island, Greece)

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Delion, GE 2010 (Delesi, Greece)



Anthedon, GE 2003 (Anthidonia, Greece)

Remains of ancient breakwaters



Anthedon, GE 2015 (Anthidonia, Greece)

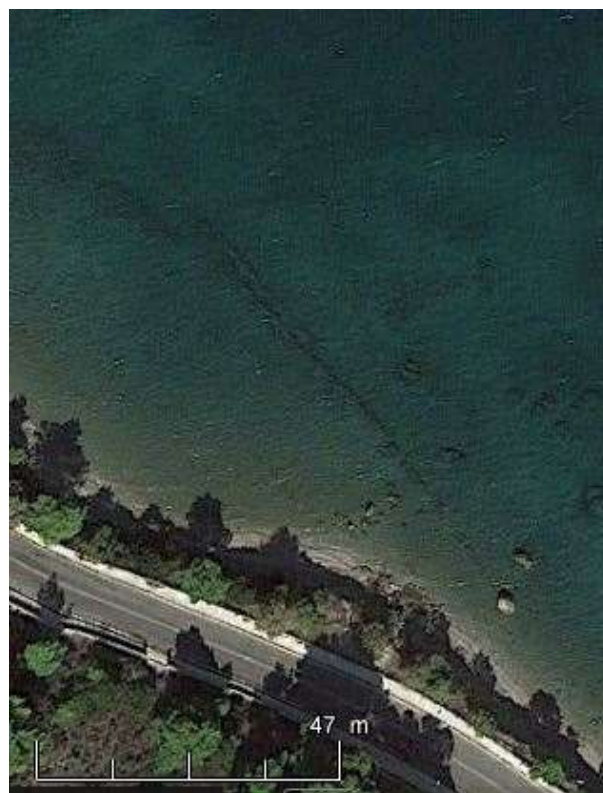


Kenchreai, GE 2013 (Kenchreai, Greece)

Remains of ancient breakwaters



Enopia, GE 2011 (Egina island, Greece)

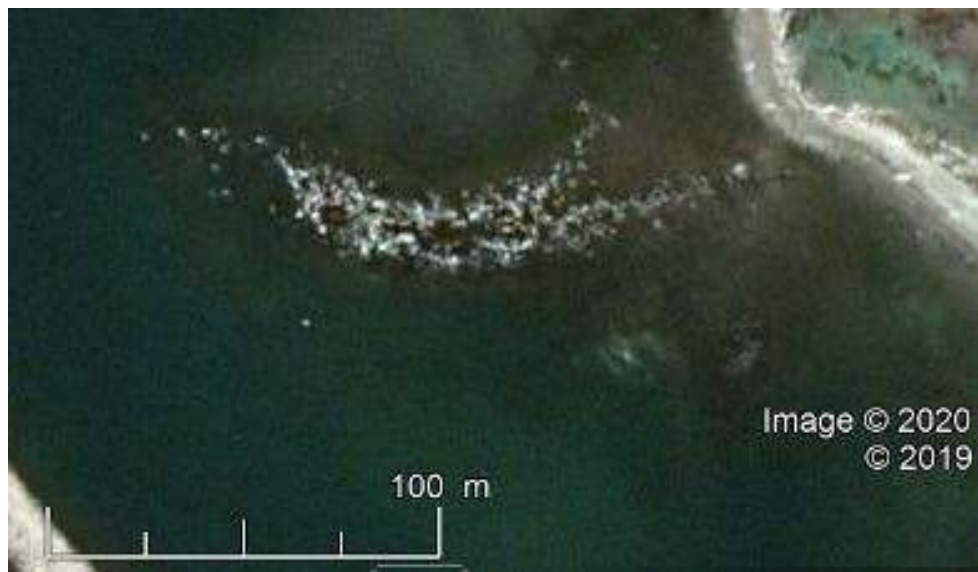


Hieros Limen, GE 2014 (Kamaraki-Vlastos, Greece)

Remains of ancient breakwaters



Eretria, GE 2018 (Eretria, Evia, Greece)



Abdera, GE 2019 (Avdira, Greece)

Remains of ancient breakwaters



Methone, GE 2013 (Modon, Peloponnesus)



Andros, GE 2003 (Andros island, Greece)

Remains of ancient breakwaters



Delos, GE 2004 (Delos island, Greece)



Rhenaia, GE 2014 (Rinia island, Greece)

Remains of ancient breakwaters



Thassos, GE 2009 (Thassos island, Greece)



Thanos, GE 2009 (Lemnos island, Greece)

Remains of ancient breakwaters



Hephaistia, GE 2009 (Lemnos island, Greece)



Neftina, GE 2009 (Lemnos island, Greece)



Sotiras, GE 2009 (Lemnos island, Greece)



Mitylene, GE 2006 (Lesbos island, Greece)

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Skiathos, GE 2016 (Skiathos island, Greece)

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Psyra, GE 2010 (Psara island, Greece)



Pythagoreion, GE 2014 (Samos island, Greece)

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Cisamo, GE 2013 (Kissamos-Kastelli, Crete)



Cisamo, Hampsä 2006 (Kissamos-Kastelli, Crete)

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Dia insula, GE 2013 (Isle of Dia, Crete)



Nirou Khani, GE 2018 (Crete)

Remains of ancient breakwaters



Chersonisos, GE 2002 (Hersonissos, Crete)



Hierapytna, GE 2010 (Ierapetra, Crete)

Remains of ancient breakwaters



Lasea, GE 2004 (Chrysostomos, Crete)



Plakias Beach, GE 2015 (Plakias, Crete)

Remains of ancient breakwaters



Amathonte, GE 2003 (Amathonte, Cyprus)



Paphos, GE 2002 (Paphos, Cyprus)

Remains of ancient breakwaters



Kourion, GE 2011 (Episkopi Phaneromeni, Cyprus)



Galata, GE 2016 (Galata, Bulgaria)

Remains of ancient breakwaters



Tieion, GE 2012 (Filyos, Turkey)



Calpe, GE 2013 (Kerpe, Turkey)

Remains of ancient breakwaters



Sirakayalar, GE 2013 (Turkey)



Caesarea Germanica, GE 2013 (Kapanca, Turkey)

Remains of ancient breakwaters



Daskyleion, GE 2011 (Ergili, Turkey)



Plakia, GE 2017 (Kursunlu Manastir, Turkey)

Remains of ancient breakwaters

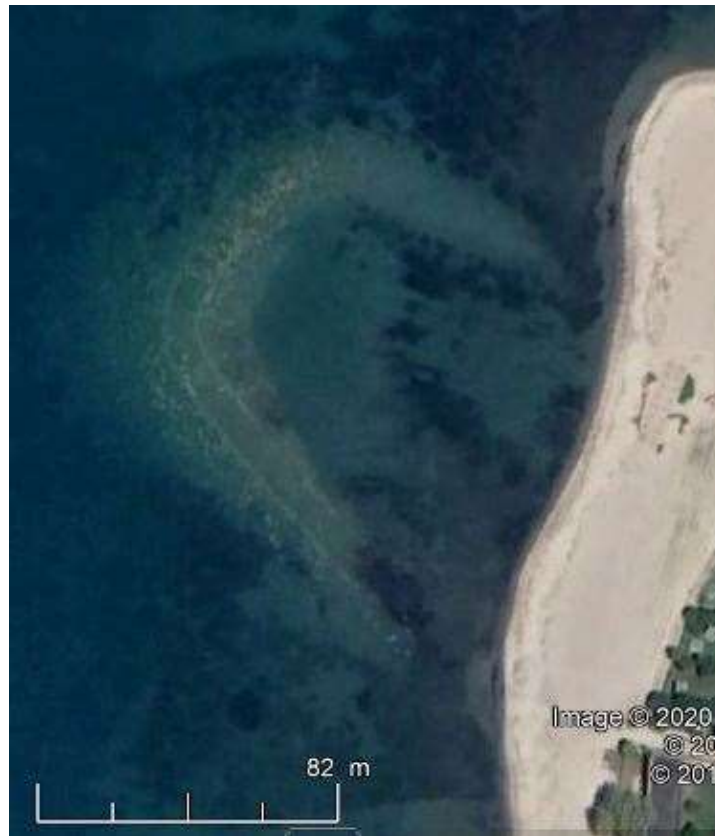


Elaious, GE 2009 (Abide, Turkey)



Assos, GE 2006 (Assos, Turkey)

Remains of ancient breakwaters



Adramyttium, GE 2019 (Ören, Turkey)



Kane, GE 2006 (Karadag, Turkey)

Remains of ancient breakwaters



Elaia, GE 2016 (Kazikbaglar, Turkey)



Myrina, GE 2006 (Aliaga, Turkey)

Remains of ancient breakwaters

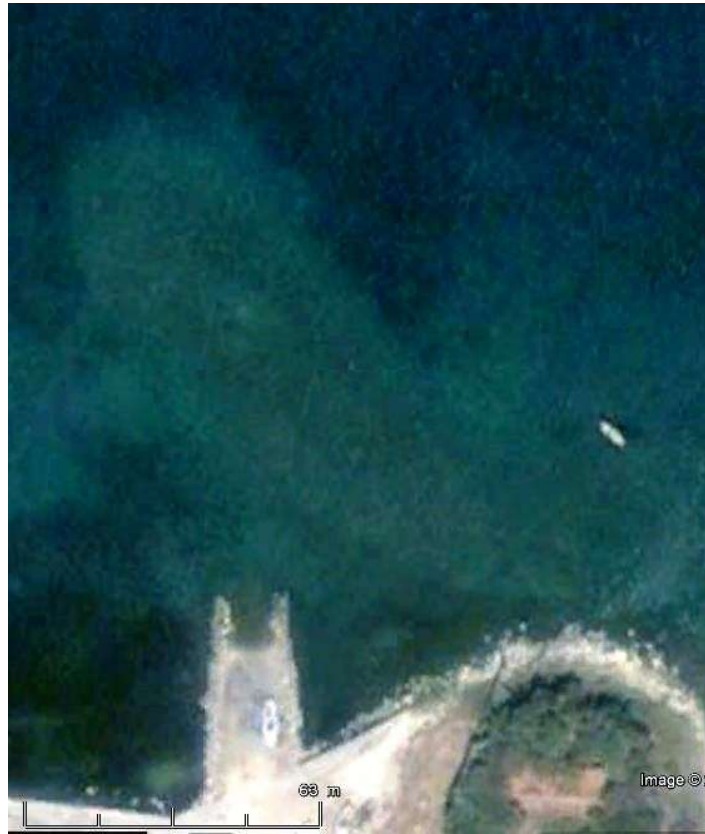


Kyme, GE 2006 (Nemrut Limani, Turkey)



Klazomenae, GE 2006 (Karantina island, Turkey)

Remains of ancient breakwaters



Klazomenae, GE 2002 (Liman Tepe, Turkey)



Klazomenae, Sahoglu 2011 (Liman Tepe, Turkey)

Remains of ancient breakwaters



Myndus west, GE 2018 (Gümüslük, Turkey)

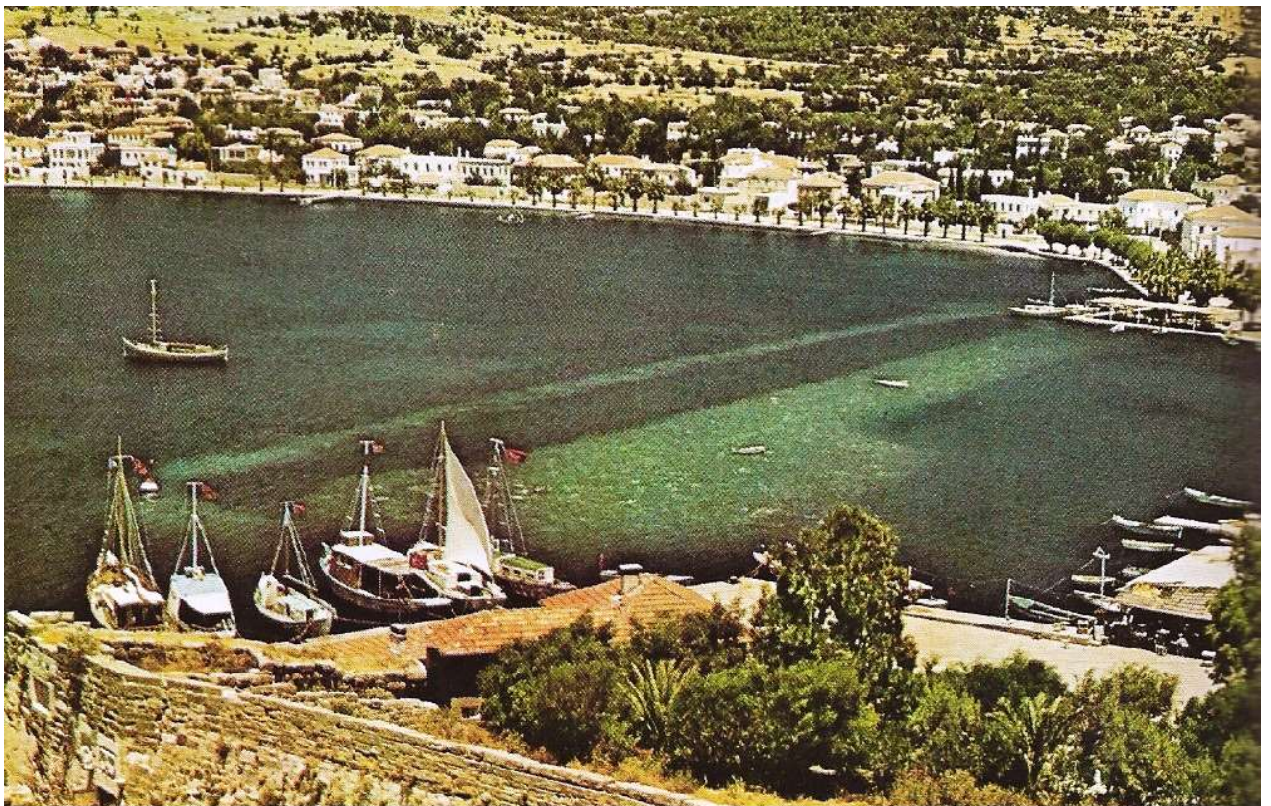


Myndus, GE 2011 (Gümüslük, Turkey)

Remains of ancient breakwaters



Halicarnassus, GE 2006 (Bodrum, Turkey)

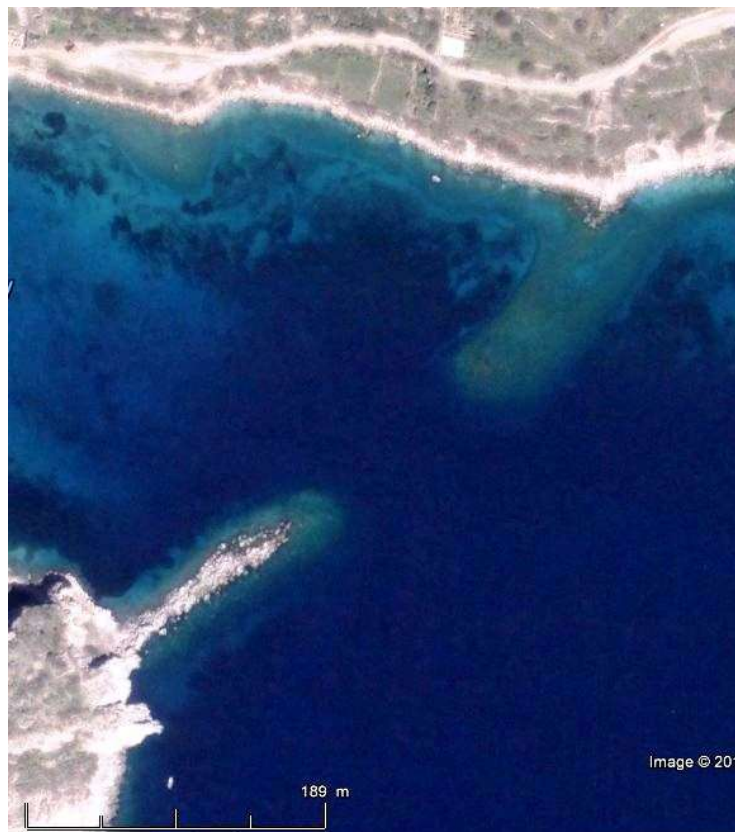


Halicarnassus, Flemming 1969 (Bodrum, Turkey)

Remains of ancient breakwaters

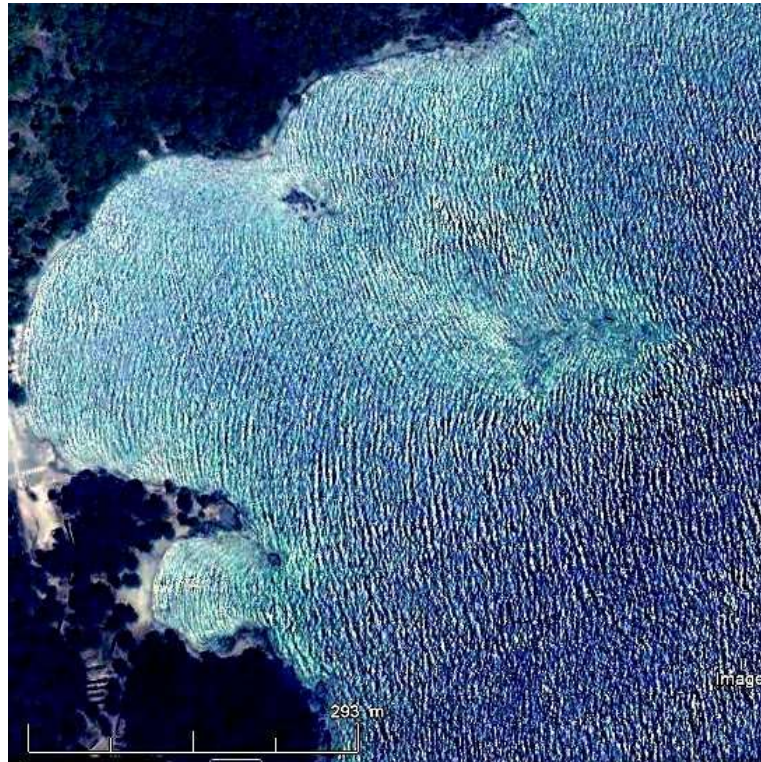


Iassos, GE 2002 (Kıyıkışlacık, Turkey)



Knidos, GE 2005 (Cnide, Turkey)

Remains of ancient breakwaters



Phaselis, GE 2002 (Tekirova, Turkey)



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Magydos, GE 2007 (Antalya, Turkey)



Side, GE 2011 (Selimiye, Turkey)

Remains of ancient breakwaters



Ptolemais, GE 2015 (Aynaligöl bay on Cape Figla, Turkey)



Corycus, GE 2004 (Kizkalesi, Turkey)

Remains of ancient breakwaters



Pompeiopolis, GE 2004 (Viransehir, Turkey)



Seleukia Pieria, GE 2008 (Seleukia, Syria)

Remains of ancient breakwaters



Tyre south, GE 2016 (Sour, Lebanon)



Akko, GE 2010 (Acre, Israël)

Remains of ancient breakwaters



Caesarea, GE 2010 (Caesarea Maritima, Israël)



Wadi al-Jarf, GE 2004 (Gulf of Suez, Egypt)

Remains of ancient breakwaters



Charmothas, GE 2017 (Sharm Yanbu, Saudi Arabia)

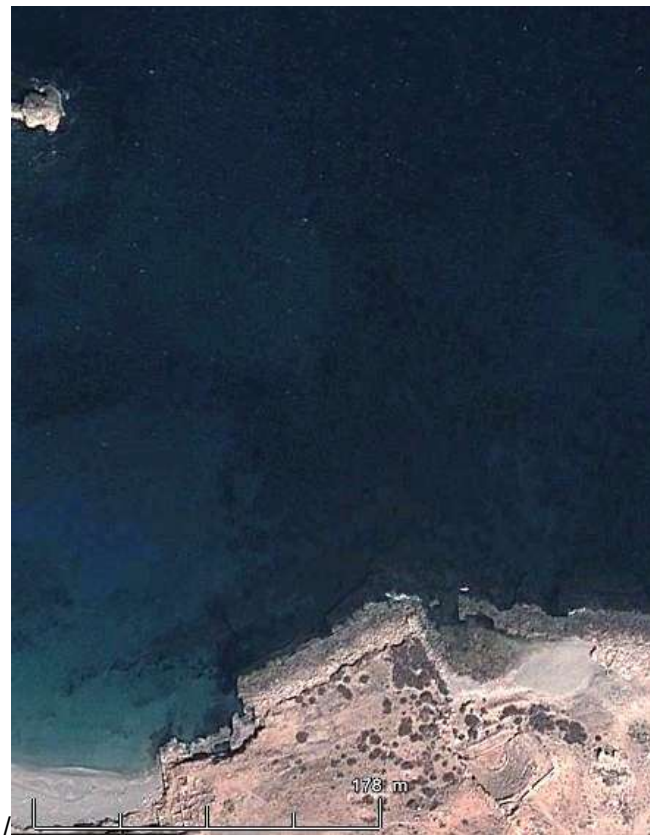


Pharos, GE 20/1/2017 (Alexandria, Egypt)

Remains of ancient breakwaters

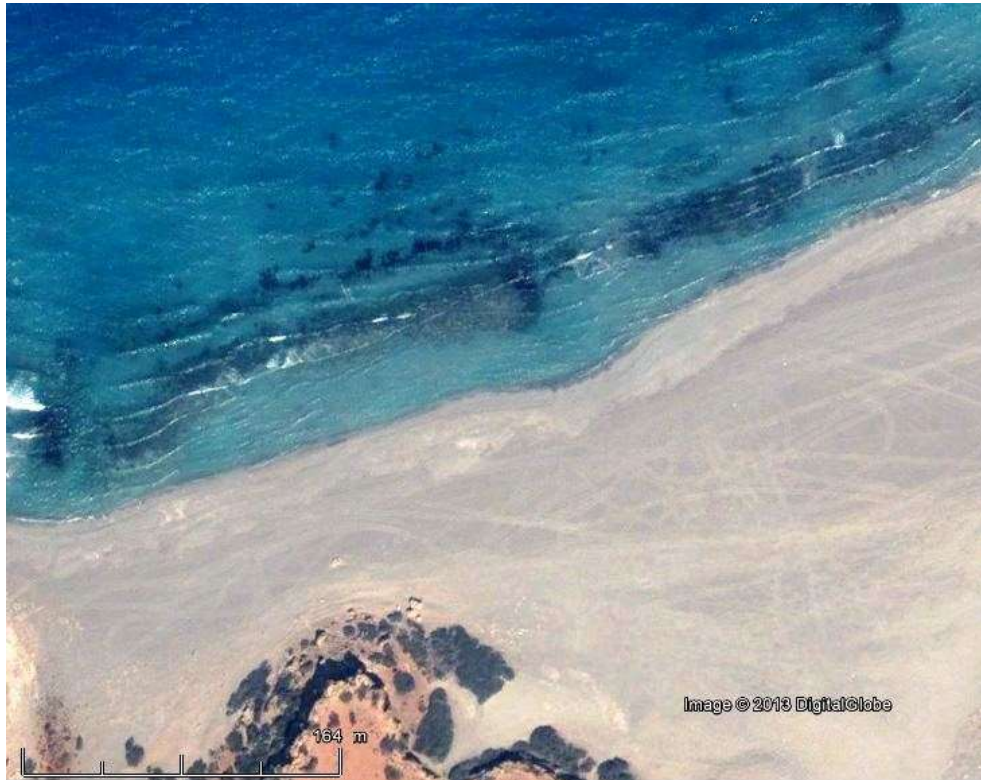


Chersonesos, GE 2020 (Cape Agami, Egypt)



Apollonia, GE 2010 (Susah, Libya)

Remains of ancient breakwaters

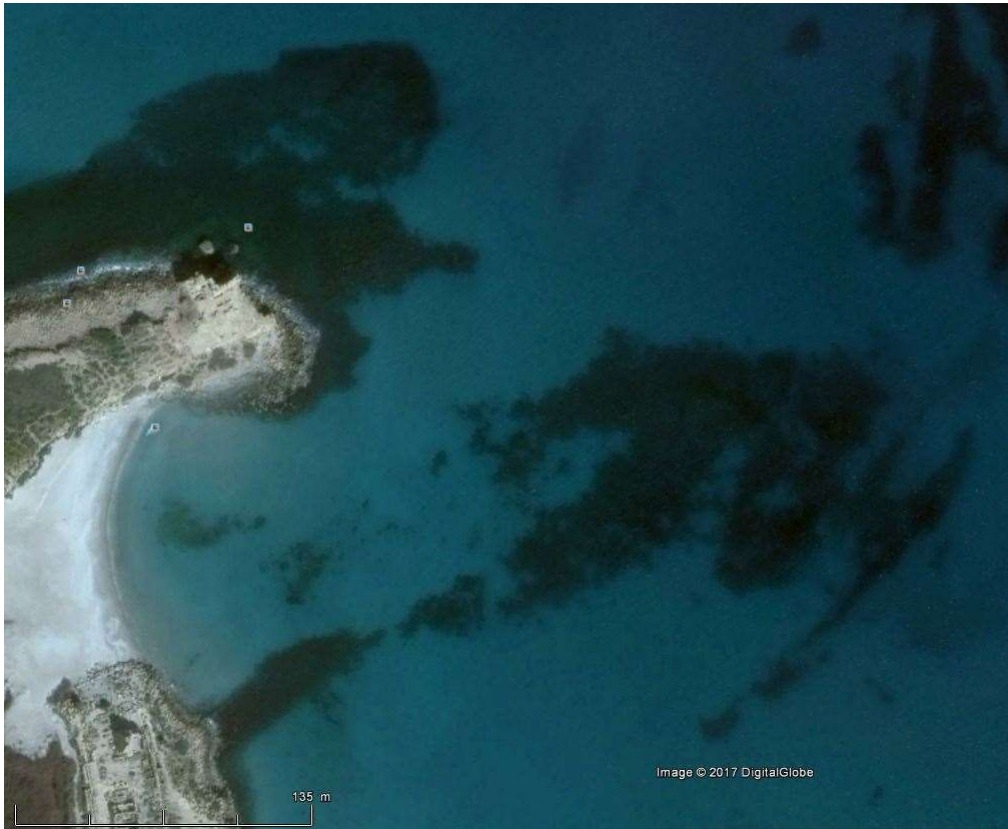


Kainopolis, GE 2004 (Maaten al Uqla, Libya)



Ptolemais, GE 2009 (Tolmeita, Libya)

Remains of ancient breakwaters



Leptis Magna, GE 2016 (Lebda, Libya)



Leptis Magna, de Graauw 2005 (Lebda, Libya)

Remains of ancient breakwaters



Sabratha, GE 2013 (Sabratha, Libya)



Gigthis, GE 2010 (Bou Ghrara, Tunisia)

Remains of ancient breakwaters



Acholla, GE 2018 (Ras Boutria, Tunisia)

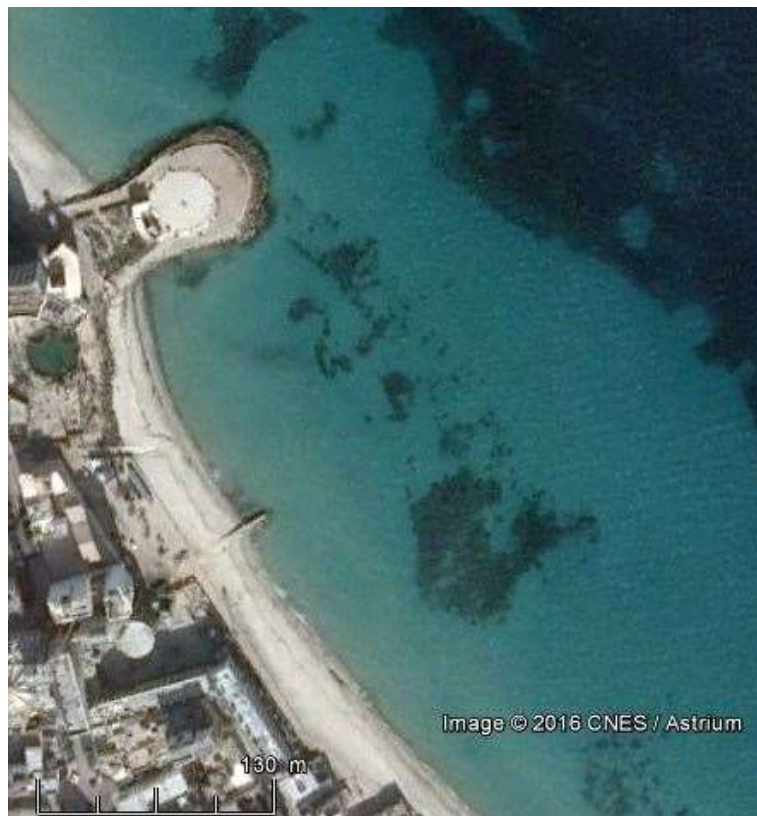


Syllectum, GE 2012 (Salakta, Tunisia)

Remains of ancient breakwaters



Thapsus, GE 2009 (Bekalta, Tunisia)

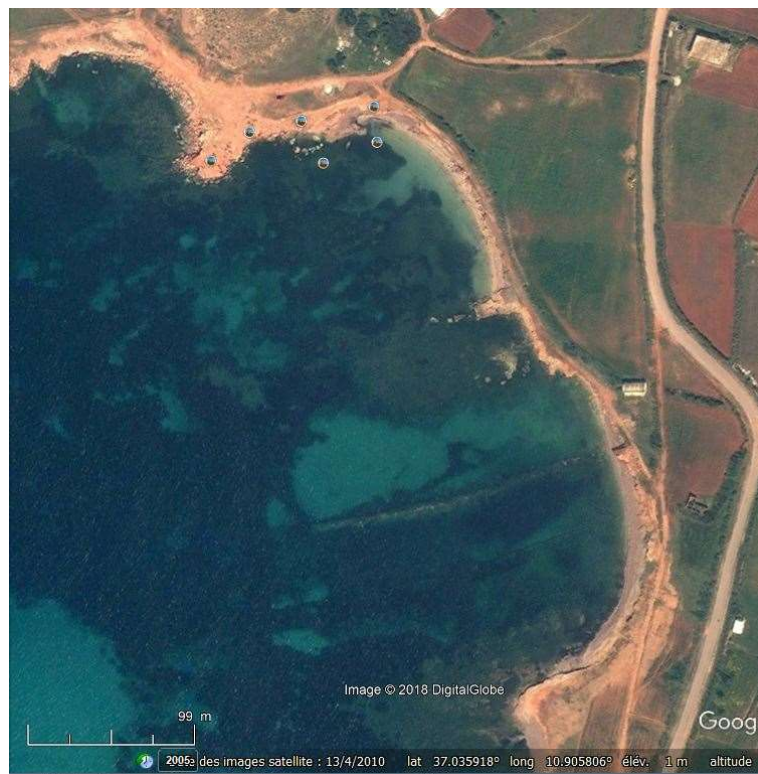


Hadrumete, GE 2014 (Sousse, Tunisia)

Remains of ancient breakwaters



Leptiminus, GE 2011 (Lamta, Tunisia)



Sidi Daoud, GE 2010 (Sidi Daoud, Tunisia)

Remains of ancient breakwaters



Sidi Daoud, GE 2014 (Sidi Daoud, Tunisia)



Carpis, GE 2009 (Sidi Raïs, Tunisia)

Remains of ancient breakwaters



Carthage, GE 2015 (Carthage, Tunisia)



Iol-Caesarea, GE 2003 (Cherchel, Algeria)

Remains of ancient breakwaters



Iol-Caesarea, GE 2013 (Cherchel, Algeria)