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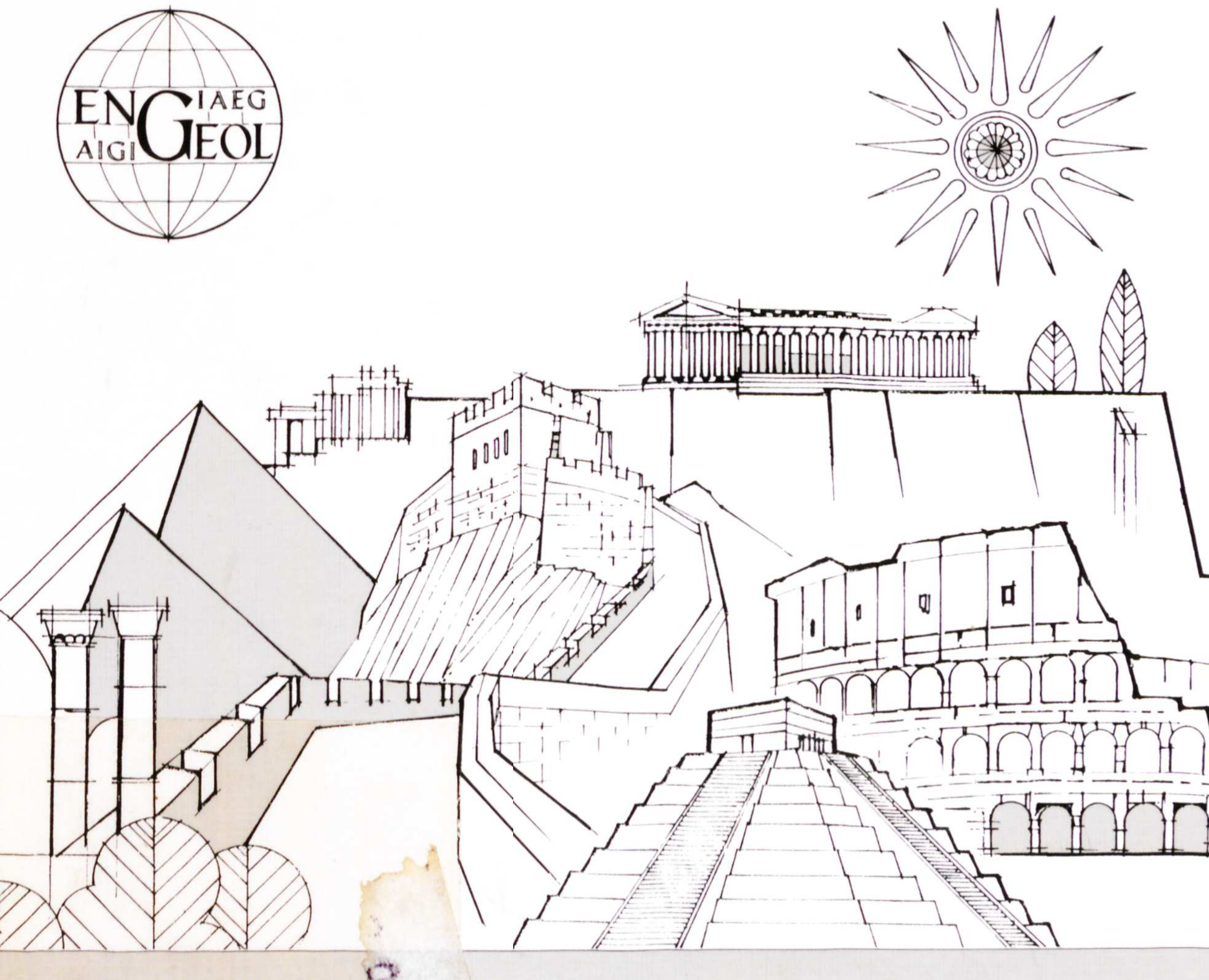

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The ancient port of Amathus (Cyprus) – Its construction, foundation conditions and final abandonment

L'ancien port d'Amathus (Chypre) – Sa construction, ses conditions de fondation et son abandon

P.Michaelides
Geological Survey Department, Cyprus

ABSTRACT: The building stones for the moles of the port of Amathus are dressed blocks of a strong, massive, bioclastic reef limestone of Upper Miocene Age with a weight of up to 2.5 t (2500 Kg), extracted from an adjacent quarry within the "Koronia Formation". The moles were founded directly onto a weak, compressible sandy stratum of the Recent Marine Deposits, characterised by high liquifaction potential when dynamically loaded. The possible reason of the port abandonment could be a gradual and regional tectonic lowering of the sea bottom (still in progress) of the Limassol Bay and/or differential settlements due to the weak foundation stratum in the vicinity of the port possibly accompanied by liquifaction phaenomena during a strong seismic event between the 6th and 7th cent. A.D.

RESUME: Les pièrres de construction des jetés du port d' Amathonte se dressent des solides pièrres massives calcaire recifal du Miocène, extraites d' un quarrière adjacente de la "Formation Koronia". Les jetés furent fondé directement sur un faible stratum de sable compressible des recents depôts marins caractérisés par une haute liquèfaction potentièlle dûe á une compression dynamic. La raison possible de l' abandon du port pourait être un abaissement régional tectonique des fonds marins de la baie de Limassol et/ou à la tassement dûe an faible stratum au voisinage du port propablement accompagnié par liquéfaction pendant de sêcousses seismiques entre 6eme et 7 eme siècles A.D.

1 INTRODUCTION

The ancient Greek port of Amathus is one of the best preserved, man-made ports in the Mediterranean and is situated about 12 Km east of Limassol, on the south coast of Cyprus (Fig. 1). Archaeological evidence suggests that most probably the port was constructed in the 4th century B.C. whilst the island was under Ptolemy I or Demetrius Poliorketes (hellenistic period), Ref. 5,6, 7,8. Its construction, if it was ever finished, served probably the safety needs of their fleet, whilst its use was for a very limited time. The port was finally abandoned between the 6th and 7th centuries A.D., just before the Arab invasions.

The Amathus port is the subject of extensive submarine archaeological research, carried out between 1984-1986 by the French Archaeological School at Athens under the direction of J.Y. Empereur. As part of this research, the author undertook in the summer of 1986 the task of providing geological-geotechnical information for

- the construction of the port, i.e. rock-types and probable sources,
- its foundation conditions, and
- the possible reason of its abandonment.

2 DESCRIPTION OF THE PORT

The port of Amathus is almost square in shape and has to the west, south and east dressed stone moles (breakwaters). These are approx. 145, 180 and 150 m. long respectively with their tops lying 0.8 m. below sea level on the landward side and approx. 3 m. below sea level seaward.

The narrow (20 m. wide) entrance of the port, situated in the eastern mole on the side away from the prevailing southwesterly winds, indicates its military nature.

The axis of the south mole makes almost a right angle with the axis of the western mole while the angle between it and that of the eastern mole is about 100°. The best preserved moles are to the east and west.

Extra protection against the winds and the associated wave action was provided for the outer side, especially the south-west corner of the south mole, by a layer of great, irregular blocks (rip-rap zone).

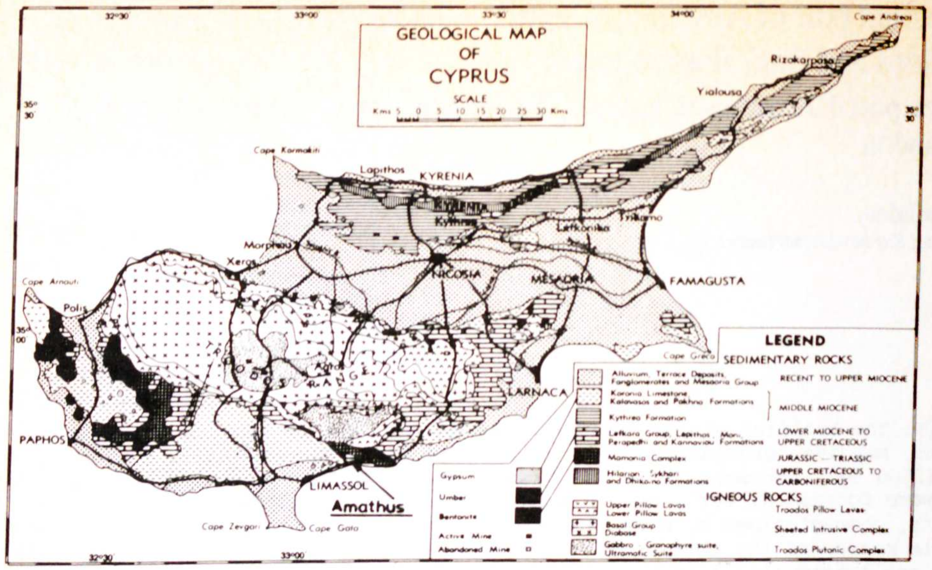

Fig. 1: Geological map of Cyprus with location of Amathus

The inner face of the moles is characterised by regular lines of dressed stones.

The north side of the port carried the terrestrial structures. These are now submerged and or totally destroyed. The port basin is partially silted with recent marine sand deposits and, together with various mole surfaces, covered by Posidonia roots (marine algae).

Fig. 2 shows in plan the general port lay-out.

3 CONSTRUCTION OF THE PORT

At Amathus, investigations have shown that only one geological formation supplied building stone for construction. Its lithology is described and the probable geographical sources (s) delineated and compared with the construction material used.

3.1 The rock types

The superimposed as great leaders, dressed and almost rectangular rock blocks forming the moles - in places up to seven courses (according to the water depth) - as well as the relatively irregular rock blocks for their protection (rip-rap) zone are of a white to light cream, strong, rather massive and generally well cemented, bioclastic reef limestone.

These building stones have max. dimensions in the range of 0.6x0.7x3.0 m (thickness x width x length) weighing up to 2.5 tonnes. Sampling and testing from these stones revealed a bulk dry density of between 1.92-2.09 t/m^3 with an average (mean) value of around 2.0 t/m^3. Considering the usual size 0.4x0.5x1.5 m of the individual blocks, their weight is estimated to be of the order of 0.5 tonnes (i.e. 500 kg).

Lithologic examination on these building stones shows that the material is highly bioclastic. The bioclastics are various fragments from shells, gastropods, corals and rare algae. They are made of crystalline calcium carbonate ($CaCO_3$) whilst the intermittent cavities are filled with carbonate mud. The lithoclasts are mostly siliceous material and contain principally quartz and feldspar crystals or consist of grey amorphous chert.

Apart from the above type, there is also (although not common) a "pseudoconglomeratic" variety, characterised by strongly cemented, highly porous and partly recrystallised matrix.

Representative samples from every rock type show however a generally constant chemical composition as to the $CaCO_3$ - and $MgCO_3$ - content. The average values range between 80-85% and 3-15% respectively.

The block dimensions of the building stones are controlled by natural dis-

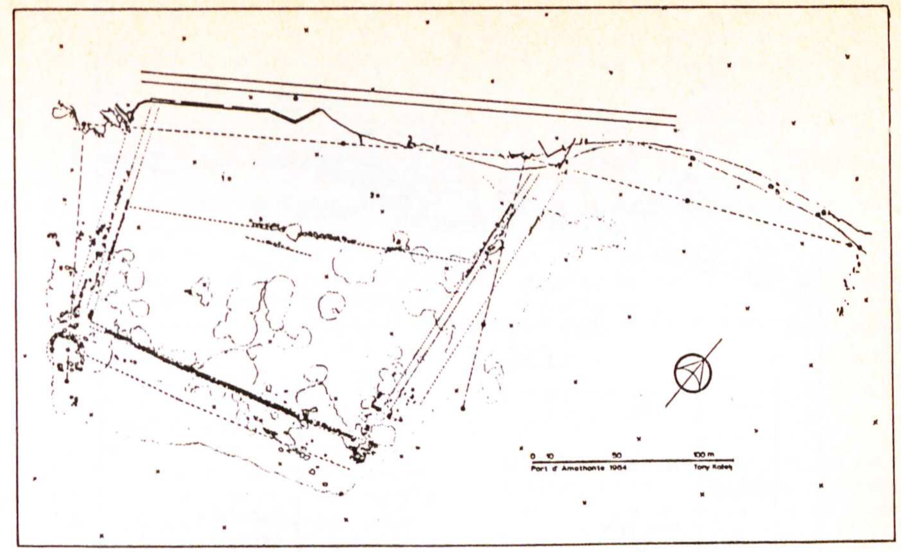

Fig. 2: Plan of the Amathus port (Fr. Petrizet and T. Koželj, 1985, Ref. 5)

continuities (joints and bedding planes). Bedding is mostly expressed in the larger blocks with uneven, rather discontinuous and poorly marked changes either in grain-size or in the relative proportions of bioclastics and lithoclastics.

3.2 Probable sources

There is a distinct similarity between the above described rock types and the bioclastic reef (or fore reef) limestone of Upper Miocene Age, the so called "Koronia Formation", which outcrops just north of the Amathus port (Fig. 3).

This formation lies conformably and with a sharp boundary on the marls of the Middle Miocene Pakhna Formation. It is well exposed, dipping gently (10^o) to the south and forming the prominent hill on which the acropolis of ancient Amathus rests. The rock is in general white to light cream coloured, very thick -, flaggy - bedded, in places massive and recrystallized. It contains also a number of fossils , mainly fragments of shells, gastropods, corals and algae. The stratification is defined by small changes in grain-size and or by interbedding of thin chalk and marly chalk bands. These chalks mark sharp and relatively continuous bedding along which easy separation is possible. This separation is strengthened by vertical, widely spaced (0.5-0.8 m) jointing striking to various directions, allowing in the thicker beds a relatively easy extraction of large but irregular rock blocks. However, the high rock-hardness (although variable) is helpful in dressing suitably dimensioned rock blocks.

Cementation is more or less variable but generally high to very high in the lower parts of the formation, where it becomes very massive and homogenous in fabric.

The Koronia Formation is finally covered by cemented (by $CaCO_3$) sandy gravels - conglomerate with igneous, well rounded clasts (gravels and pebbles) and secondary limestone, "havara". Their thickness is of the order of 1.0 m and represent probably in Pleistocene) raised, badly sorted River Terrace Deposits, a result of intense erosion due to the rapid uplift of the Troodos massif (Fig. 3).

This erosion has cut through the Koronia limestone into the underlying Pakhna marls forming in places prominent cliffs with well developed natural quarry faces. The most prominent of them and very close to the shore line which could have provided the construction material of the Amathus port, is to be found on the west bank of an erosion quarry, just west of the acropolis of Amathus and north-west of its port. At this locality, a most likely ancient quarry with the working face (looking to the east) is almost vertical, about 15 m in max. height and more than 100 m in length. It consists of a number of secondary quarry faces

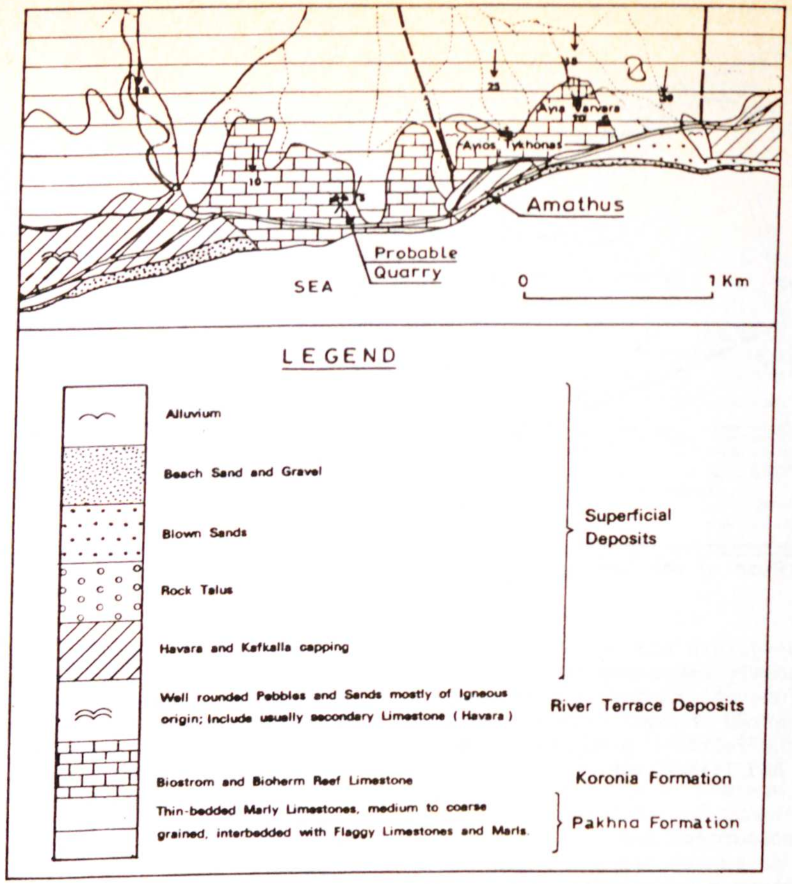

Fig. 3: Geological map of the Amathus area

within the bioclastic Koronia limestone which dips here gently (10^o) to the south. It still bears joint marks of the metal rock picks used to cut and extract the rock blocks.

The uppermost part of the quarry face (below the one meter thick River Terrace Deposits) is a sequence of thinnly - very thinnly bedded, more or less chalk bands with intermittently thin - laminated, off-white clayey marls. This chalky horizon was apparently unsuitable for extracting large, high-strength rock blocks, so it is believed that the material was only used for paving stone.

The evidence from this quarry as well as the distinct lithological-petrographical similarity between the insitu rock at the quarry site and the building stones of the moles provide sufficient proof as to the origin and probable sources of the construction material of the port. No other ancient quarries were located in the vicinity of Amathus area. As the required rock was available in sufficient quantity within a short distance from the port, it was superfluous to look for it elsewhere.

Thus the basic criteria of the ancient engineers, such as the minimal distance (haulage) and the accessibility between the quarry site and the construction site were met.

Other criteria which they must have taken into account in determining the source, would have included soundness, uniformity, resistance to weathering, chemical stability (especially against sea water), sufficient strength, limited porosity, relatively low specific gravity for easy handling and workability.

Their choice of the Koronia limestone as a source shows them to have chosen the best available material.

4 FOUNDATION CONDITIONS

In the moles (breakwaters) only seven courses of ashlar blocks (dressed rectangular rock blocks) have survived. These rest on greenish-grey, loose and, locally highly organic, and therefore highly compressible, silty sand. This deposit is of Pleistocene-Holocene Age and represents the main component of the Recent Marine Deposits which cover the bottom and coastal area of the Limassol - Amathus Bay. It contains a variety of clastic products (including gravels and boulders) which are set in a silty sand matrix and were derived from the Troodos Ophiolite Complex (situated to the north of Amathus) as well as from the circum - Troodos Sediments, mainly chalks, limestones, sandstones, cherts and gypsum. The majority of these clasts were brought into the Limassol Bay by the Garyllis and Yermasoyia rivers and were subsequently redistributed eastwards along the coastal zone by littoral drift. Their thickness in the area of Amathus is unknown but by extrapolation from adjacent areas this would not exceed ten meters.

From a geotechnical point of view, these Recent Marine Deposits (especially their silty-sandy component) are very susceptible to long term and especially to immediate settlements. The reason for this behaviour is their loose to very loose, uncompacted nature, the lack of cementation and their locally high organic content (partially decomposed Posidonia roots).

All of these characteristics typify a foundation material of low bearing capacity. This characterisation is strengthened further by very low N values obtained from Standard Penetration Tests in similar sediments immediately to the west of Amathus.

Where these sediments are exposed above sea level, they have the same low bearing capacity and liquifaction potential (high groundwater level) as their submerged equivalents.

Evidently the breakwater structures and the on-land port facilities were subject to rapid differential settlements especially when shaken by earthquakes. This is borne out from observations on the southern breakwater where the basal course of ashlar blocks has sunk into the foundation stratum, with individual blocks lying at different orientations.

It is apparent from the above that the foundation conditions of the Amathus port and its terrestrial facilities were problematic and very sensitive to rapid or longterm settlements.

Similar settlements can be observed where the eastern and western moles join the one on the south side of the port but most significantly the southern mole has the most extreme differential readjustments. This is not surprising since this breakwater is the highest of the three and therefore exerts a much greater load on the foundation stratum.

Other reasons for the chaotic orientation of the blocks in the southern mole may be failure during construction or an inability on the part of the construction people to maintain even courses in the much deeper waters that occur seaward.

5 POSSIBLE REASON (S) OF THE PORT ABANDONMENT

It is evident from on site submarine archaeological investigations that Amathus port was abandoned in the late 6th or early 7th century A.D. This conclusion is based to a large extent on the (total?) absence of archaeological findings of this period.

Possible reason (s) of the abandonment (apart from economic, commercial and military reasons) could be:-

1. A continuous, long term settlement of the marine and on-land port structures which apparently created serious economic and technical problems for continuous restoration. This type of settlement occurs locally around the coasts of Cyprus and is superimposed on a rather rapid, episodic uplift of the whole island that dates from the late Miocene, some 10 m.y. ago. Such areas of submergence have been documented south of Paphos, Salamis as well as Amathus and may have been triggered by movement along faults as a result of earthquakes. At Amathus, beach-rock carrying pot fragments is found below sea level where it has moved after its formation above water.

2. A gradual sinking of the weak foundation stratum of the port after its overloading by the heavy rock-block courses of the moles. This overloading could lead to an acceleration of the sinking tendency in the area of Amathus port and produce serious construction damages, which if not (technically and financially) remediable, forced the Amathusians to abandone their port. This "geotechnical hypothesis" could be combined with

3. A short, extremely rapid sea bottom settlement - liquifaction as a result of a strong seismic event which gave to the Amathus port the "final kick" to its existence. This "earthquake-hypothesis" is highly probable considering the catastro-

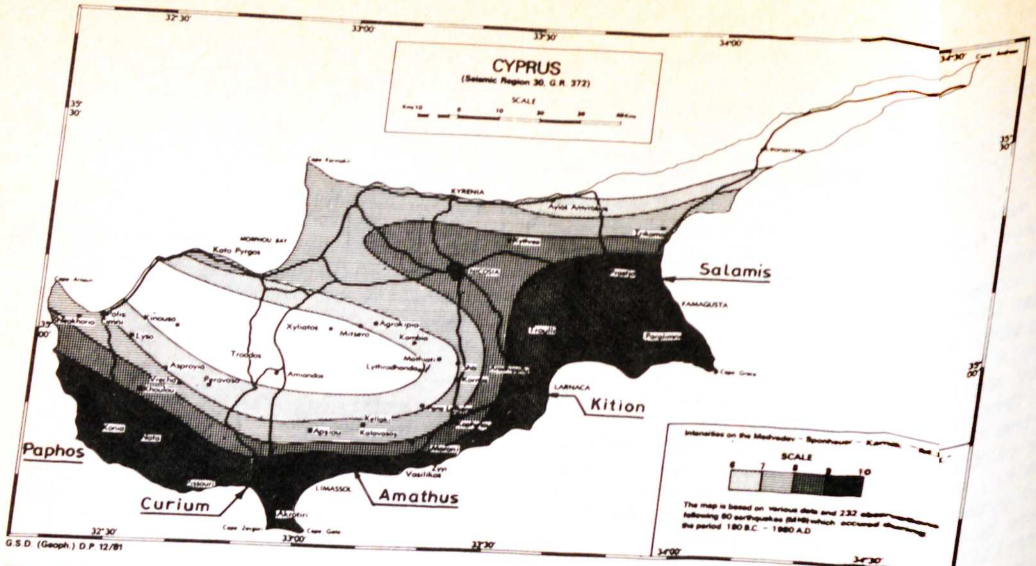

Fig. 4 : Isoseismal map of maximum observed intensities (J. Neophytou, 1980)

phic earthquakes of:-
332 A.D. at Paphos,
342 A.D. at Paphos and
365 A.D. at Curium,
which damaged very seriously the above cities and their ports (especially the earthquake of 342 A.D.). Also, the seismo-tectonic position of Limassol-Amathus Bay which is in the same high seismic risk zone (Fig. 4) with intensities between 9-10 on the M.S.K. (Medvedev-Sponheur-Karnik) scale as the above cities, greatly supports the "earthquake-hypothesis". Ancient cities along the whole south coast of Cyprus (e.g. Paphos, Curium, Kition, Salamis) were often destroyed by earthquakes and the demize of Amathus and its port could not be an excemption.

Regarding the possible extraction of rock blocks from the Amathus port for the construction of Suez Canal, this has nothing to do with the port-abandonment since the Suez Canal was constructed some 1000 years later.

6 CONCLUSIONS

The geological investigation carried out so far and the criteria used have been sufficiently accurate in answering questions about the construction, foundation conditions and possible reason (s) for the final abandonment of Amathus port.

However, it is strongly believed and suggested that the archaeological research should continue and a more systematic, surface and submarine, geological investigation be carried out aiming to give more detailed information about the whole history of Amathus port and its terrestrial structures. This coincides fully with the admirable ambition of the local society SALPA which seeks after any possible (technical and economic) support for restoration of this ancient, very well preserved port.

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