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RECONSTRUCTION OF ANCIENT CLIMATE AND HUMAN IMPACT ON THE ENVIRONMENT AT MOTYA

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The paper presents a survey and analysis of published palaeoclimatic data of the Mediterranean for the 1st millennium BC and in particular of the island of Motya, Western Sicily. Combining the results of studies on climate change in the Western Mediterranean, sea-level fluctuations and sea temperature in the Sicilian Channel, and the full range of data from palaeobotanical and vegetation analyses, we try to propose a reconstruction of the ancient climate and environment, in consideration of the human impact.

Keywords: paleoclimate; archaeobotany; sea-level; Holocene; Sicily

1. INTRODUCTION: MOTYA, SICILIAN CHANNEL, MEDITERRANEAN SEA, AND THE CLIMATE VARIABILITY IMPACT

In attempting to reconstruct the climate of the island of Motya at the time of Phoenician colonisation and in the period that followed, it becomes essential to have the results of studies on climate change in the Mediterranean, sea-level fluctuations in the Sicilian Channel and the full range of data from archaeobotanical and vegetation analyses carried out during research on the island. This information indirectly provides us with an insight into climatic-environmental aspects based on the presence or absence of native species or the introduction of certain archaeophytes.

The semi-enclosed configuration of the Mediterranean Sea makes this an extremely vulnerable region to modern and past climate changes. The strategic transitional zone that the Mediterranean occupies, between North African and European climates, from the arid zone of the subtropical high to the humid north-westerly air flows, gives the Mediterranean a particular interest, unravelling climate tele-connections during periods of climate variability. Several studies carried out in different marine sites have focused on the short-term climate variability over the last millennia but so far, any general reconstruction of the regional temperature evolution has not been attained. Compared to other regions of the world, the Mediterranean is characterised by a wealth of archaeological studies and historic documents, as well as a paleoclimatic data, which make it a perfect case study to investigate the potential influence of climate on civilisations. In fact, the mid-Holocene phase is particularly challenging as it coincided with important cultural changes (human civilizations) that developed around the Mediterranean area[1]. The study of fossil archives remains the only valid tool to reconstruct past environmental and climatic changes particularly for the pre-Roman and Roman periods[2].. However, its application in the marine realm is compromised by the difficulty to obtain marine records with a high enough resolution, and clear proxy signals that can be reproduced among different records. Climate variability of this period is often close or within the proxy errors and uncertainties in its interpretation in terms of seasonality and/or local oceanographic processes, making it difficult to read in terms of

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[1] Roberts *et al.* 2011.

[2] Mc Cormick *et al.* 2012.

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regional climate evolution. Nevertheless, this is a critical information to identify past interactions between climate changes and evolution of human societies and their adaptive strategies. At the heart of the Mediterranean Basin, Sicily is highly sensitive to climate change due to the complex synoptic atmospheric configuration of the region. This pivotal geographic location exposes forest ecosystems to the influence of the southern subtropical climatic regimes and the northern temperate conditions of Europe, resulting in a fragile and dynamic environment susceptible to rapid hydroclimatic variations[3]. Furthermore, Sicily has long been a Mediterranean cultural crossroads, acting as a gateway between East and West as well as a melting pot of ancient civilizations[4]. The long history of human land use on the island left a strong imprint on ecosystems, affecting the vegetation structure and driving the evolution of rural landscapes.

The case of Motya fits into this scenario. It is a protected archaeological area known to have been one of the most prosperous Phoenician colonies in the Western Mediterranean, already inhabited before the arrival of the Phoenicians at the beginnings of the 8th century BC.[5] The island is located in the province of Trapani (Sicily, Italy), ∼ 0.5 km far from the Western Sicilian shoreline, in a lagoon area called the “Stagnone di Marsala” (∼ 3 × 7 km of size), characterized by a very shallow seafloor where salt ponds are active since historical times. Like all Mediterranean coastal areas, Motya is sensitive to climate change, VLM of natural and anthropic origins and the consequent relative sea level rise.[6] In this sense, Motya plays a crucial role for the reconstruction of past relative sea levels in the Mediterranean basin, filling the gap between geological and instrumental estimates. Thus, analyses conducted on climatic variations in Western Sicily, or research on the warming of the sea close to the Sicilian Channel and its rise over the centuries,[7] combined with wide-ranging and narrow-ranging palaeobotanical analyses, support the attempt to reconstruct the island’s ancient climate and the impact that human groups had on the original environment.

2. THE ANALYSIS OF LAST MILLENNIA SEA SURFACE TEMPERATURE (SST) EVOLUTION IN SUPPORT OF THE RECONSTRUCTION OF ANCIENT CLIMATE

Phenomena of climatic instability during the Holocene also affected this area of the Mediterranean, and in particular Western Sicily, likely to have been characterised by lower surface water temperatures and prolonged and more intense action of winds from the northern quadrants. Even in this case, however, it is not clear what the impact of these climatic variations was on the continental environment. For instance, several continental records, including data of fossil pollen, lake sediment geochemistry and speleothems, indicate an abrupt decrease in precipitation starting from the mid-late Holocene period.[8] The trend of gradually decreasing rainfall has had an obvious impact on the appearance of vegetation, overlaid by the strong anthropic impact due to land use for agricultural and livestock farming purposes.

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[3] Michelangeli *et al.* 2022.

[4] Norwich 2015.

[5] Nigro 2013; 2014; Nigro - Spagnoli 2017.

[6] Antonioli *et al.* 2017; Anzidei *et al.* 2014; 2017; 2018; Marsico *et al.* 2017; Lambeck *et al.* 2011; Woppelmann - Marcos 2012.

[7] Incarbona *et al.* 2010.

[8] Sadori - Narcisi 2001; Sauro *et al.* 2005; Frisia *et al.* 2006; Zanchetta *et al.* 2007; Sadori *et al.* 2008.

Regarding the Sicilian Channel and thus the area in which the island of Motya is included, we can make use of various studies on the surface warming of the Mediterranean Sea and its variations, which relate to a general oscillation of the ancient climate. In this direction, a new reconstruction of the SST (Sea Surface Temperature) record generated from the central part of the Mediterranean Sea based on the Mg/Ca ratios measured in the planktonic foraminifer *Globigerinoides ruber* covering the last 5000 BP is of great support to the subject of this research.[9] This research provides the basis for discussing the main characteristics of SST during the last two millennia, from which it appears that the Roman period is the warmest period, with interesting implications for the development of civilisation in the Mediterranean region.

The Mediterranean Sea is an anti-estuarine semi-enclosed sea that can be subdivided into two sub-basins, the Western and Eastern Mediterranean separated by the Sicily Strait sill.[10] Low salinity surface waters, called Modified Atlantic Water (MAW), enter in the Mediterranean Sea from the Strait of Gibraltar. MAW flows along the Algerian coast as the coastal Algerian Current and separates into two branches at the entrance of the Sicily Strait.[11] The Strait of Sicily represents a physical barrier (about 500 m deep) of the Eastern Mediterranean and implies considerable control over the biogeochemical processes occurring within the eastern basin. Most of the MAWs cross the Sicilian Channel to the south,[12] while the rest flows into the Tyrrhenian Sea,[13] channelling right along the north-western coast of Sicily and thus lapping the waters where the island of Motya rises (fig. 1).

The comparison of the Mediterranean SST records highlights very distinct regional patterns before the onset of the Greek period, with an overall cooling trend in the Aegean Sea, a warming trend in the Sicily Strait and more stable conditions in the Alboran Sea. In the Sicily Channel, between the base of the record and the beginning of the Bronze Age period, the Mg/Ca *G.ruber* SST signal shows two warm events, at ca. 2913 BC and ca. 2040 BC, respectively. The first warm event, documented in the study record of Sicily Channel, although it does not fall within the 95% CI, has been tentatively associated to the Copper Age warm phase (ca. 2913 BC).[14] This event chronologically corresponds to a warming in the Aegean Sea SST record and agrees to the beginning of a gradual aridification process described in northern Egypt.[15] The second one (Early Bronze Age, ca. 2040 BC) is associated with a further aridity phase, as documented by the strong decrease in arboreal pollen in the Central Mediterranean.[16] This latter event, chronologically corresponds to the fall of the ancient Egyptian Reign and to the end of the Mesopotamian civilization, associated with strong famines related to a dry climate and a strong aridity.[17] Later, Mg/Ca *G.ruber* SST warmed between 1800-1100 BC indicating relative warm conditions during Late Bronze Age (ca. 1100 BC) documented in the whole Mediterranean basin. Significant cultural changes

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[9] Margaritelli *et al*. 2020.
[10] Pinardi *et al*. 2015.
[11] Millot 1987.
[12] Bethoux 1980.
[13] Robinson *et al*. 1999.
[14] Margaritelli *et al*. 2020.
[15] Kaniewski *et al.* 2010.
[16] Di Rita *et al*. 2018.
[17] Behringer 2009.

are documented during this period, in fact, historical records indicate the collapsed several civilizations.[18] Most of the Greek Bronze Age Palatial centres were destroyed and/or abandoned. The Palatial centres were hit hard by the increase in aridity and the collapse of agriculture production making impossible for the population to sustain themselves.[19] The transition from Bronze Age to Iron Age chronologically approximates the short-term cooling event associated to the Homeric (ca. 800 BC) grand solar *minimum*. During this period, associated to negative NAO values, the climate conditions were favourable for the agriculture expansion in the Eastern Mediterranean.[20] Compared to the subsequent Roman period, the Mediterranean was characterized by a colder phase from ca. 500 BC to 200 BC, predating the rise of the Roman Empire. From a chronological point of view, this interval corresponds to the beginning of the so-called "sub-Atlantic phase",[21] characterized by a cool climate and rainy winters which was propitious for the expansion of the Greek, Etruscan and Roman civilizations.[22] During this period, global glacier advances are also documented, and a negative NAO phase is recorded.[23] The cool and humid climate of the sub-Atlantic phase lasted until ca. 100 BC and covered the entire period of the Monarchy in Rome. In addition, this period is characterised by a short-term cooling event associated with the Greek (ca. 350 BC) solar *minimum* (fig. 2). However, at ca. 400 BC, cultural changes were synchronised across the Mediterranean region. The Greek and Phoenician colonies expanded, and Rome and Carthage began their epic rise, a situation coincident with the establishment of more homogeneous temperature conditions across the Mediterranean regions.[24]

According to this framework, based on the study of marine warming, the phase of Phoenician colonisation of the island of Motya corresponds to a period of cold weather that occurred around 800 BC. It seems to coincide with a phase of climate change at the time, which resulted in a wetter Western Europe and a drier Eastern Europe. This had far-reaching effects on human civilisation, some of which are recorded in Greek mythology and the Old Testament[25]. But above all, it is from 500 BC until 200 BC that there is a general climatic cooling with rainy winters and a generally cold climate, corresponding in the history of Motya with the destruction by Carthage and subsequent reconstruction.[26]

3. THE SEA LEVEL AND COASTLINE OSCILLATION STUDY AS AN INDEX OF ENVIRONMENTAL CHANGE

For the purpose of reconstructing the climate and environment that characterised the island of Motya at the time of Phoenician colonisation (from the beginning of the eighth century BC.), we cannot fail to consider a series of studies on the rise of the sea level over the centuries, which have provided a series of fundamental data on the original coastline and consequently on the configuration of certain archaeological evidence. Due to the low elevated

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[18] Weiss 1982.

[19] Drake 2012.

[20] Kaniewski *et al.* 2010.

[21] Zolitschka *et al.* 2003.

[22] Shaw 1981.

[23] Mayewski 2004.

[24] Roberts *et al.* 2011.

[25] Martin-Puertas *et al.* 2012.

[26] Nigro 2022.

topography, the island and the archaeological ruins are very sensitive to the sea level changes, in particular to the ongoing sea level rise due to climatic change and VLM. One of the main types of evidence of this phenomenon is the ancient Punic causeway connecting the northern gate of Motya to the nearby Sicilian coast, presently submerged to about 1.1 m.[27]

The three principal contributions to sea level change, measured with respect to land, along the Italian coast, are (i) the sea level response to the past glacial cycle, including the response to the most recent glacial unloading of the major ice sheets and the European Alps and the response to the ocean floor loading by the melt water, the glacio-hydro-isostatic and eustatic contributions; (ii) changes in ocean volume in more recent times from thermal expansion (recent glacier melting etc.), and (iii) vertical land movements, including uplift as in Calabria and Sicily and subsidence as in the northern Adriatic.[28] For the Italian coast, tectonic stability is assumed when the Last Interglacial (LIg) shorelines occur at about 6 m above present sea level. Where the LIg markers occur above or below this level, it is assumed that the area has been subjected to uplift or subsidence.[29] These analyses allow assessments of sea-level rise from 20,000 years (fig. 3). These predictions are for the isostatic-eustatic components from the last glacial cycle only and their variability from site to site reflects both an approximately north-south component from the increasing distance from the former northern ice sheets and a more variable component from the water-loading contribution. Along the entire Italian coast, sea level is rising because of this ongoing response to the past deglaciations at rates of up to 0.6 mm/year.[30]

The study, which analysed the impact of climate change-induced sea-level rise on the coastal heritage site of Motya, made it possible to assess the effects of this phenomenon on human settlement over the past 2400 years, as well as to predict the scenario for the coming decades. A detailed flooding scenario for 2100 from direct observations and two models, taking into account the contribution of Vertical Land Movements (VLM), is provided.[31] The surface topography is derived from a novel high-resolution/high-accuracy digital surface model (DSM), which was performed through an Unmanned Aerial Vehicles (UAV) survey,[32] whereas the rate of VLM was estimated by the analysis of geodetic data at three Continuous Global Positioning System (CGPS) stations located close to the island. To estimate the local mean sea level and to correct the tide level (TL)[33] at the epoch of UAV survey, the hydrometric recordings of the nearest sea level gauge station located at Porto Empedocle (Sicily), were used. The results of this analysis have provided a fairly clear picture of the effect of climate change on the retreat of the coastline from the values that existed between the 8th and 7th centuries B.C. and have provided archaeologists with useful information to better clarify the use of some of the structures discovered. This is the case of the Kothon, a sacred freshwater pool at the centre of a monumental circular sanctuary hosting three large temples[34] and which today is intermittently connected to the sea, depending on the level of

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[27] Schmiedt *et al.* 1972.

[28] Lambeck *et al.* 2011.

[29] Ferranti *et al.* 2006; Nisi *et al.* 2003.

[30] Lambeck - Purcell 2005.

[31] Ravanelli *et al.* 2019.

[32] Barradas Gutierrez 2018.

[33] Antonioli *et al.* 2015; Sammari *et al.* 2006.

[34] Nigro 2022

the tide level. The sea-level curve proposed[35] estimates a sea-level rise for Motya of about 3.0 m over the last 3500 years (fig. 4), in agreement with other RSLC estimates for the late Holocene in the central Mediterranean region.[36] Under the assumption that the VLM has been stationary during this long-time interval, we observed that the Kothon was approximately 2.2 m above past sea level.[37] This process of uplift and consequent advancement of the sea along the island's coastal shoreline has been facilitated and accelerated by the anthropogenic impact on the territory, which has led to the elimination of the native coastal vegetation that constituted a natural barrier against the advancement of the sea, in the form of the coastal arboreal dune (fig. 5).

4. THE CONTRIBUTION OF ARCHAEOBOTANICAL ANALYSES TO CLIMATE AND ENVIRONMENTAL RECONSTRUCTION AND HUMAN IMPACT ASSESSMENT

A further and essential strand of research that provides valuable information for the reconstruction of the ancient climate and environment of Motya and Western Sicily is based on archaeobotanical and palynological analyses. Past natural climate variability and human impact on ecosystems can be profitably studied from sedimentary archives of lakes, bogs, mires, and seafloor. Pollen analysis of sediment cores collected in natural deposits allows the detection of vegetation and climate trends, long-term ecological processes, and legacy effects operating over long periods of time. It provides a detailed picture of the composition, structure, and distribution of past natural vegetation and highlights the diffusion of cultivated *taxa* in relation to agricultural practices and historical land use management. Recent palynological investigations from continental sites have provided crucial information about the Holocene vegetation of Sicily in a wide range of environments, from the coast to the highest elevations. However, a comprehensive view of the regional vegetation dynamics is still missing. Furthermore, these paleoenvironmental reconstructions do not provide a sufficiently detailed picture of the Late Holocene, preventing a deeper understanding of the historical vegetation dynamics in relation to cultural and climatic events.[38]

In Western Sicily, from as early as the 6th millennium BC, strong hints in the palynological and sedimentary records suggest the beginnings of the aridification process[39]. This process became much more severe in the last two millennia and has been a major driver in soil erosion and valley-filling phenomena. Erosion events appear to have been episodic and punctuating a longer-term relative equilibrium but were gathering pace and severity from later prehistoric times onwards, which is indicative of intensifying human activities, especially arable agriculture. The establishment of settlement sites such as Mokarta in the later 2nd millennium BC and Motya and Monte Polizzo in the 1st millennium BC appears to be coincident with an increasing intensity and extensiveness of clearance, diminished tree resources, the presence of cereal, fruit, and vine crops, and eroded soil aggrading in associated valleys.[40]

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[35] Lambeck *et al.* 2011.

[36] Furlani *et al.* 2013.

[37] Ravanelli *et al.* 2019.

[38] Tinner *et al.* 2009.

[39] French 2010.

[40] French 2010.

Although numerous archaeobotanical studies have been performed on Sicilian material,[41] studies on early to mid-1st millennium BC material in Sicily are scarce and only concern the sites of Rocchicella-Palike near Mineo,[42] Monte Polizzo (Salemi) and Selinunte.[43] Pollen records confirm a heavy environmental impact during the period of Phoenician occupation with the opening of coastal forests in both inland and coastal Sicily.[44]

The archaeobotanical analyses are carried out at the archaeological site of Motya with a multidisciplinary approach, including anthracology, carpology and palynology, and it aims at reconstructing the land use and exploitation of natural resources on the island. Analyses focus mostly on the western slopes of the Acropolis, where a big disposal pit, dated from the end of 8th to the 6th century BC, was identified. The deposit revealed a vast assemblage of cereals (including *Hordeum vulgare, Triticum monococcum, Triticum turgidum* subsp. *dicoccum* and *Triticum aestivum/durum*), pulses (*Cicer arietinum, Lathyrus oleraceus, Vicia lens, Vicia faba* and *Vicia ervilia*) and fruits. These include *Vitis vinifera*, represented both by seeds and pedicels, and *Punica granatum*, whose spread to the Western Mediterranean is attributed to Phoenicians. Also weeds (~~*Agropyron repens*~~ *Chenopodiastrum murale, Lolium temulentum, Phalaris* sp. and others) were found. In terms of charcoals, the most represented taxa are *Olea europaea* and *Quercus* sect. *suber* (evergreen oaks, most likely *Q. ilex*).[45]

This kind of analysis informs us about the impact that the inhabitants of the island have had on the surrounding environment, either in terms of cultivation, or in terms of introducing new plant species. Anthracological data help to complete the local environmental picture, with findings of *Pistacia lentiscus, Olea europaea, Erica multifora, Erica arborea, Juniperus* sp. and evergreen oaks. Only the first three currently grow on the islet, while *Erica arborea* and *Juniperus* species grow no closer than 40 km and 100 km from Motya, respectively. *Olea europaea*, with abundant charcoals, and still cultivated on present day Motya, is surprisingly lacking in the pollen diagram, which describes an open environment characterized by strong anthropogenic activities. The high charcoal percentage of evergreen oaks, plants today absent on Motya and currently showing a scattered occurrence along the coast facing the Marsala Lagoon, indicates that it was a wood-type of preference. Finally, the retrieved fragments of the "montane type" of pine probably issue from imported material. Remarkably, the finding of *Pinus pinea* represents the oldest for this species in the Central Mediterranean.[46]

Based on the evidence reported, it is possible to compare Motya's past environment with the present one. The present-day lack of *Juniper* sp. could be due to burning, as this plant is a less efficient re-sprouter after fire than other woody species of the maquis, like heaths and lentisk. Similar considerations could explain the present lack of *Erica arborea*, whose disappearance is likely ascribable to either land over-exploitation, aridification or a combination of both processes.[47]

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[41] Mercuri *et al.* 2015.

[42] Castiglioni 2008.

[43] Stika - Heiss - Zach 2008; Stika - Heiss 2013.

[44] Sadori - Narcisi 2001; Sadori *et al.* 2013.

[45] Moricca 2021; Moricca *et al.* 2021.

[46] Moricca *et al.* 2021.

[47] Gianguzzi 2012.

5. CONCLUSION

In conclusion, the attempt to reconstruct the ancient climate at the time of the Phoenician colony of Motya needs the support of various disciplines that study in particular the warming of the Mediterranean Sea, shoreline fluctuations and archaeobotanical remains. These are all areas of research that can provide some data to support hypotheses about climate change and how it may have influenced and modified the natural environment. In addition to this, man's response to adapt to his environment and thus the need to modify it in accordance with economic and social development must be considered.

From the constantly evolving study on sea level rise we receive numerous confirmations on the effects of climate change which over the centuries has turned towards a progressive environmental warming and therefore a constant process of aridification. We know that sea level rise is due to two main causes: thermal expansion caused by ocean warming (as water expands as it warms) and increased melting of land ice. This causes indirectly appear to us a more humid and in any case temperate climate at the time of the construction of Kothon for example, given that the analysis revealed that the shoreline was placed at about 2.2 m below the current sea level at the time of the construction of the Kothon, inferring that it could not use as a harbour, even for small boats.

And to conclude, we are helped by a series of data obtained directly from the carpological and anthracological analyses carried out on the archaeological deposits of Motya. Also, in this case these data can indirectly provide some indications on climatic oscillations and more directly on the impact that human groups have had on the environment of the island. Past environment is inferred by anthracological and palynological evidence. Palynology allows for the depiction of a strongly anthropized Mediterranean landscape, with little to no forest cover. Anthracology helps to complete the local environmental picture, with findings of *Pistacia lentiscus*, *Olea europaea*, *Erica multiflora*, *Erica arborea*, *Juniperus* sp. and evergreen oaks. The overall weed assemblage shows similarities with the ones from the Iron Age sites of Monte Polizzo and Selinunte in Western Sicily. Furthermore, it was possible to identify some changes that occurred in time in the vegetation of Western Sicily.

The identification of some varieties of herbs such as *Cyperaceae* and *Polygonaceae* for example confirm the presence of a humid environment, with permanent freshwater or subject to extremely short periods of drying up, perhaps corresponding to the fresh-water springs found on the island.[48]. Indicators of human activity are varieties of the *Cichorioideae*, which could be linked to large areas used for lawn or pasture or only to coastal salty meadows. Some concentrations of non-pollen palynomorphs are considered indicators of marine and lake erosion which, as we know, represents one of the main effects of climate change taking place in Motya. The anthracological remains form an important part of the archaeobotanical assembly and they also inform us about the flora present on the island since most of the wood *taxa* retrieved are typical of the Mediterranean maquis and show a correspondence with the present-day flora of the Sicilian coastline, between the infra and the thermo-Mediterranean. Finally, an indicator of aridification processes is represented by the current disappearance of a series of plants present in the pollen of Motya, such as *Erica arborea,* which tells us of a profoundly different and above all less dry ancient climate. The human impact, on the other hand, seems to be witnessed by the disappearance of the *Juniper* sp., very widespread in the

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[48] Di Mauro *et al.* 2011.

Phoenician Motya and currently absent on the island, the cause of which could be linked to the fires intentionally carried out to obtain cultivation areas. From the analyzes, in fact, data emerges on the introduction of non-native species, as grapevine (*Vitis*), pomegranate (*Punica granatum*) and perhaps also Pine tree (*Pinus pinea*), very likely imported by the Phoenicians.

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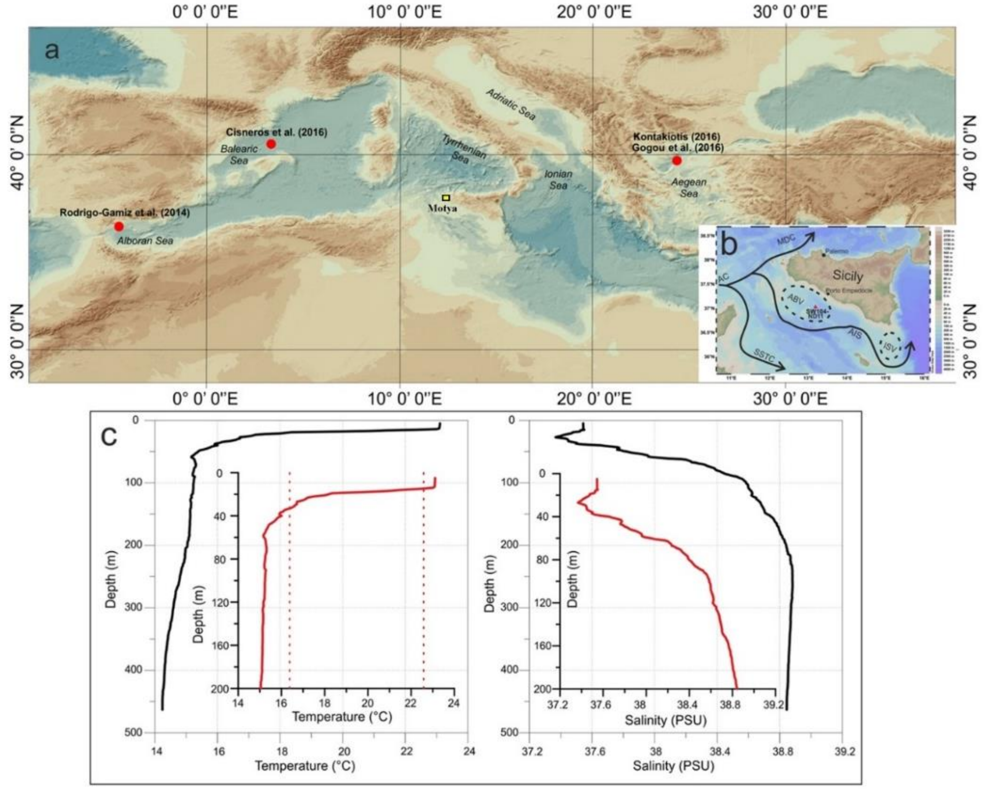


Fig. 1 - Bathymetric map of the central-western Mediterranean Sea and the Sicily Channel. Black lines follow the path of surface water circulation (Margaritelli *et al.* 2020, 2, fig. 1).

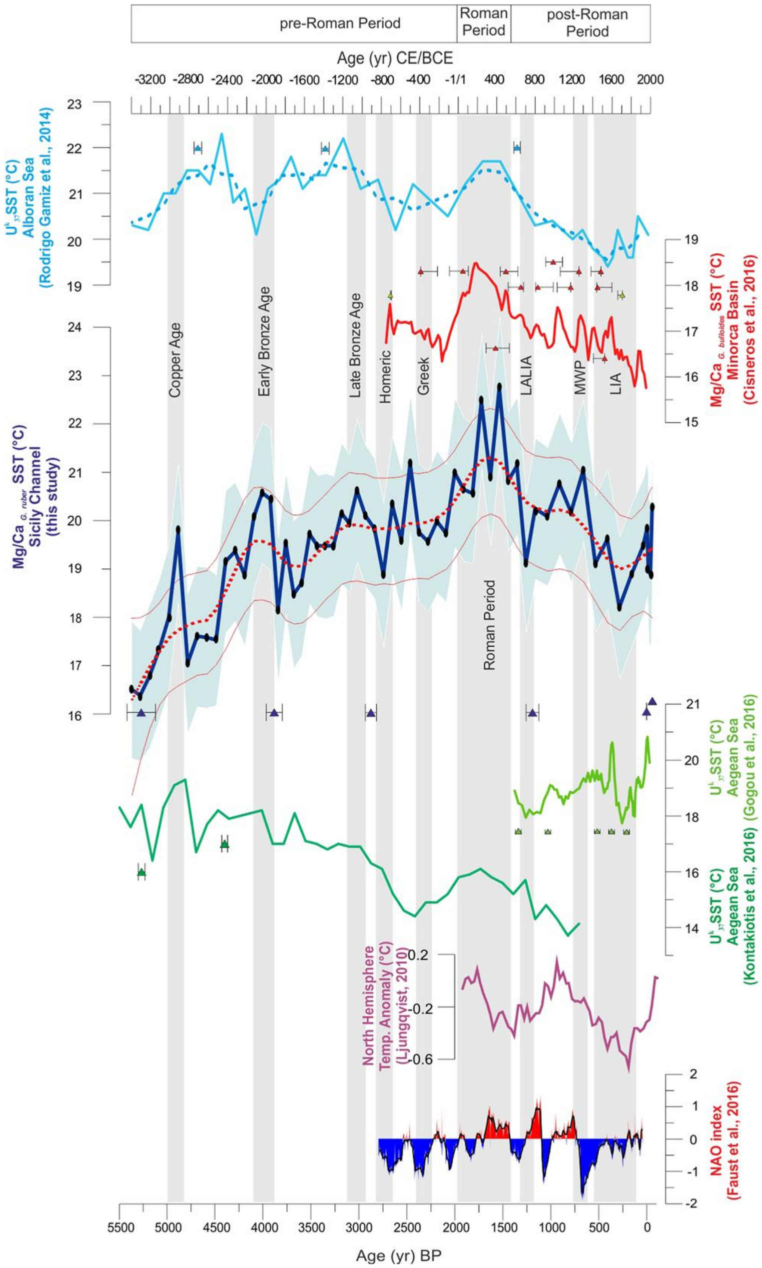


Fig. 2 -Comparison in time domain of the SSTs records from Sicily Channel (blue line) (Margaritelli *et al.* 2020, 3, fig. 2).

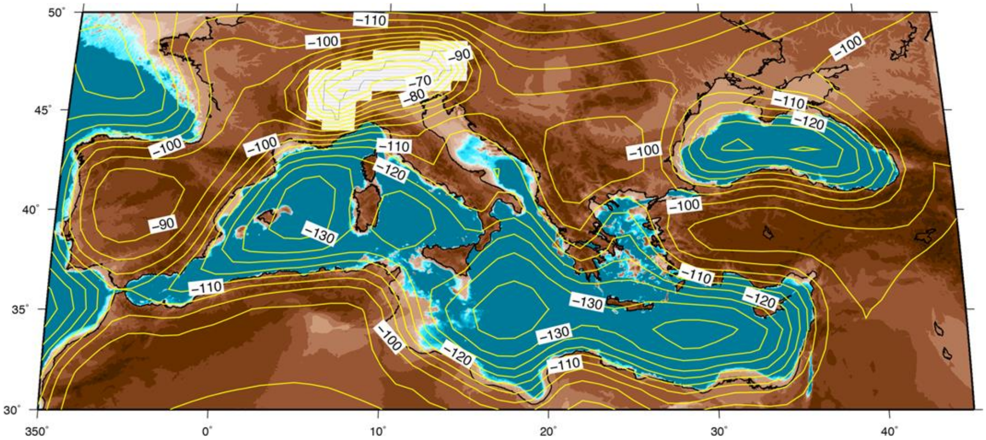


Fig. 3 - Palaeogeographic reconstruction of the Mediterranean basin for the time of the Last Glacial Maximum at 20 000 years BP, (after Lambeck - Purcell 2005, 1975, fig. 2). Contours show the sea-level change with respect to present sea level.

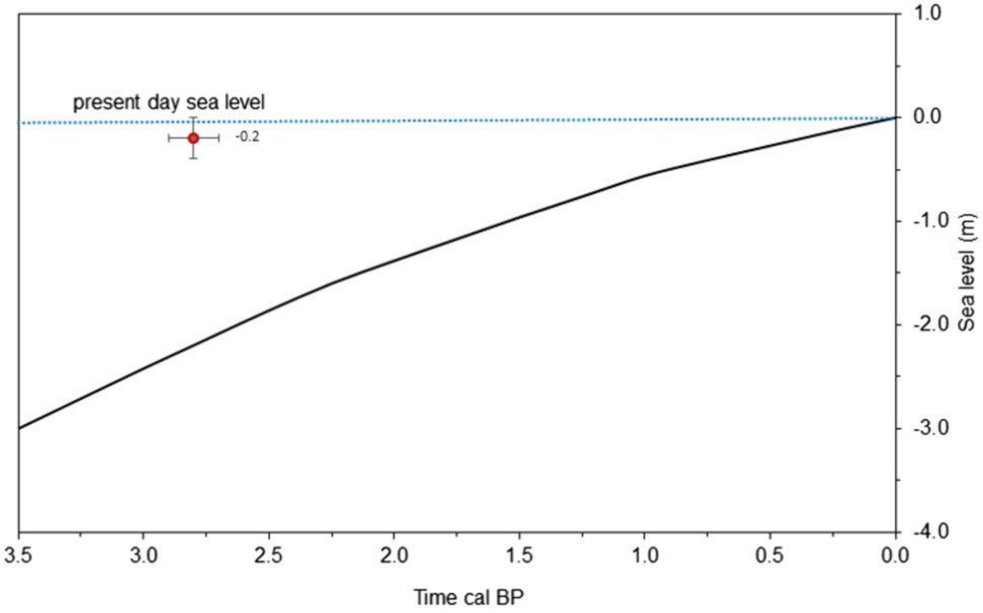
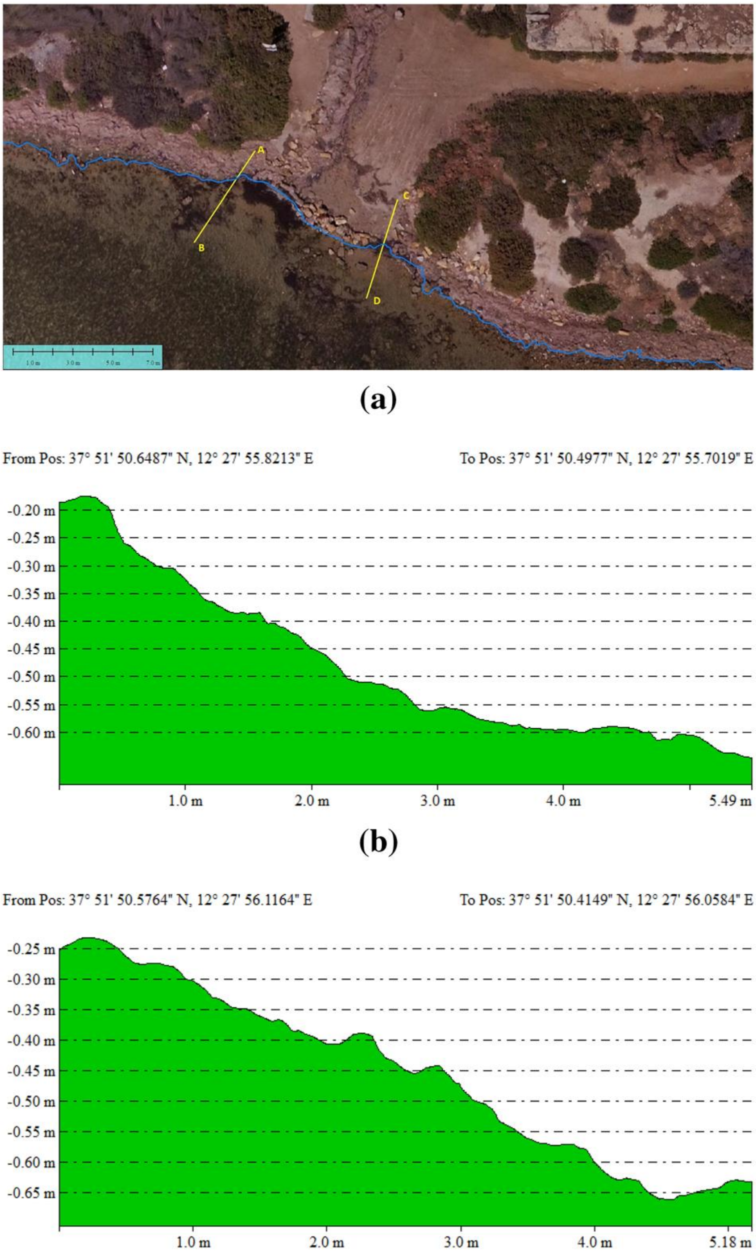


Fig.4 - The black curve is the sea-level prediction for the last 3.5 Kyears BP for Motya (Ravanelli *et al.* 2019, 752, fig. 11).



(a)

(b)

(c)

Fig. 5 - Topographic sections in the Kothon area showing the impact of sea level rise (Ravanelli *et al.* 2019, 750, fig. 5).