Why is the Maltese Archipelago so small in its physical size?

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Introduction

The Maltese Islands have undergone various physical processes over millions of years which have changed the size and the character of the islands. The most recorded factors are presented in various physical features on land and in forms of sub aerial and marine erosional structures. These features are present in numerous forms along the Mediterranean coastline and their presence help to explain the eustatic and climatic effects on the region. The Maltese archipelago is no exception to and various records are imprinted on our limestone coast which indicate the climatic variations which have acted in the past.

The late Miocene epoch was the period when the Mediterranean became a completely closed evaporation basin due to compressional tectonics between the African and Eurasian plates. This caused the build-up of salt deposits in the Mediterranean Sea, known as the Messinian salinity crisis. Such evaporites which occurred between 6.5 and 5.5 millions of years BP indicate that a warmer climatic phase was present in the Mediterranean. Warmer climates lasted up to about 3.3 million years BP, the dawning of the late Pliocene. This produced a considerable thickness of evaporitic deposits in several areas of the Mediterranean regional basin. After this, climatic cycles fluctuated through the late Pliocene and Pleistocene epochs, and long periods of cold spells were active. It is estimated that at least four main glaciations have occurred during these times. These took place in continental Europe and spread to low latitudes in the following time periods:-

- 1.6 to 1.3 million years ago
- 0.9 to 0.7 million years ago
- 0.55 to 4 million years ago
- 0.08 to 0.01 million years ago

Following the last glaciation maximum at about 18,000 years ago, the continental ice sheets and ice masses in mountainous terrains began to withdraw. Such changes did not occur everywhere at the same time nor did they proceed at equal rates. Deglaciation was progressive and various Mediterranean shorelines display evidence of different sea level stages due to the differing rates of sea level rise. Unfortunately these long records of sea level variations are hard to come by because the present earth is in an interglacial state and past syn-glacial marine terraces now lie beneath the sea. On many coasts, tectonic activity or isostatic adjustments have elevated marine terraces and it is from these that most reliable history of sea levels has recently been obtained.

The last glacial maximum lasted from *ca*. 27,000 to 18,000 BP and the subsequent sea level rise had a direct effect on the coastlines. Most clear changes are imprinted on limestone coasts which favour the development of different forms of erosion, such as wave cut platforms, notches and sea caves, which remain for long periods of time. Even loose beach deposits can consolidate rapidly in the Mediterranean climate, and are preserved for longer. However, tectonic activity can cause the uplift or submergence of the marks of ancient shorelines protecting them from the destructive impact of waves thus preserving them.

The low sea level of the final glacial period of the Pleistocene *ca.* 19,000 years ago exposed wide coastal plains that were mostly level and could be easily traveled on. In some places, land bridges formed between continents or between mainland and islands, such as those connecting Asia and North America and the European continent and the British Isles. The distance across open sea, between South Europe and Malta was bridged or greatly narrowed. Paleogeographic studies have shown that both animals and man made use of these land bridges when climate and sea levels were different.

Sea level rise in the central Mediterranean *ca.* 18,000 BP

During the last glacial maximum, the shape of the Central Mediterranean was much different than today. The east Tunisian and north Libyan coast possessed a coastal plain which was about 200 km wide and extended a long way towards Sicily and Europe. The distance between Africa and Europe was reduced to only about 60 km with several flat topped islands in between, including Malta. However, a narrow land bridge closed the Straits of Messina. This bridge, with a present depth of 90 meters and only 1 km wide must have vanished shortly after the sea began to rise probably as early as 15,000 to 14,000 years ago. (Figure 1)

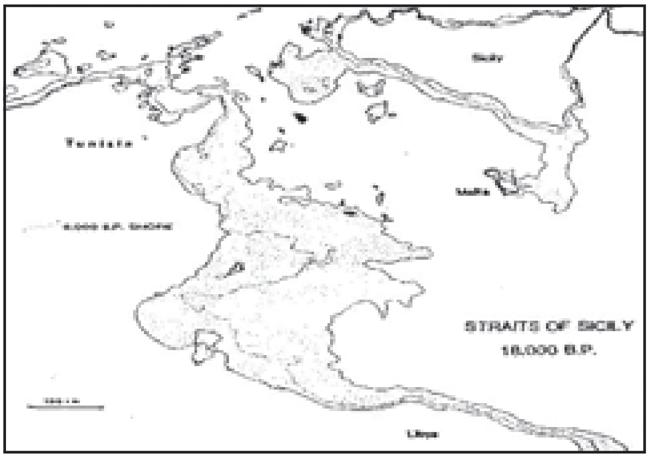

Figure 1: Sicily and North Africa at lowest sea level during the late glacial maximum. Dashed line inside the stippled emerged coastal plain represent the shoreline of 9,000 B.P. (Source: Shackleton et al 1984)

In the meantime major changes occurred in the Adriatic. A vast coastal plain occupied the northern half. The Italian margin of the southern Adriatic was also fringed with a coastal plain facing east across a narrow gulf to the lowlands streams and isolated hills of coastal Croatia and Albania. The glacial maximum of 18,000 BP clearly led to the emergence of this plain. (Figure 2)

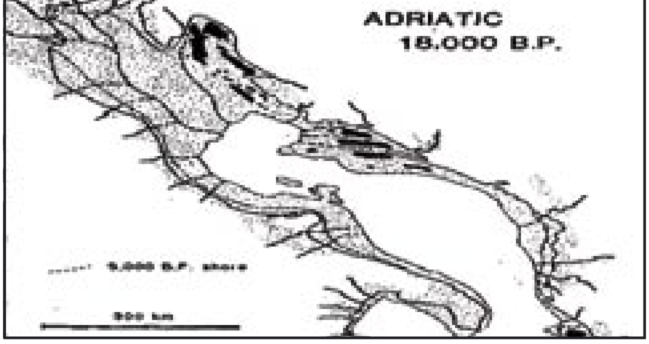

Figure 2: The Adriatic Sea at lowest sea level. Heavy dashed lines are rivers traversing the stippled coastal plain. Present Dalmation islands (in black) formed steep hills in this plain. The shore of 9,000 B.P. is a lighter broken lime (Source: Shackleton et al 1984)

Just a few millennia of rise in sea level were enough to alter the central Mediterranean coastal geography most profoundly. By 9,000 BP the broad plains had largely vanished. The intervening straits between Corsica and Sardinia, which were at a depth of 65 metres, were separated by a sea way 10 km wide and their distance from Italy had increased to 60 km. A large part of the Tunisian coastal plain had shrunk to produce a distance of 200 km between Sicily and North Africa (Shackleton J. *et al* 1984). (Figure 3)

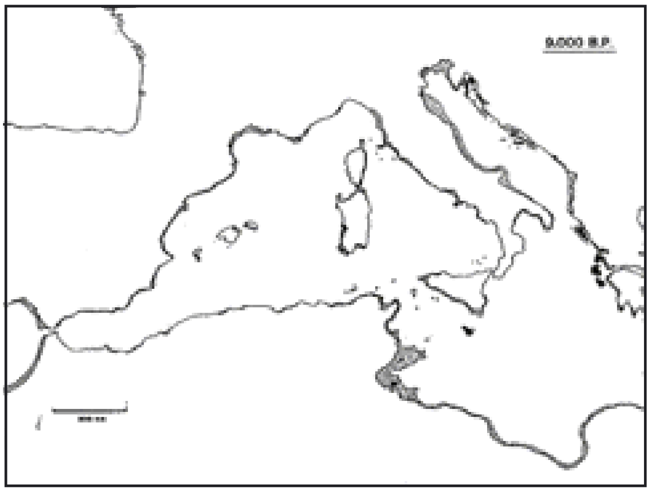

Figure 3: The Western Mediterranean near the end of the rapid rise of the post-glacial sea at 9,000 B.P. Remnants of the late glacial coastal plain are stippled. (Source: Shackleton et al 1984)

Traces of four earlier Pleistocene Mediterranean sea levels were present throughout the Mediterranean. These are now at 90 to 100m Sicilian period; 55 to 60m Milazzian period; 28 to 30m Thyrrenian period, and 18 to 20m Monastirian period. Each shoreline was believed to correspond to the maximum level of a marine transgression the higher the levels being the older ones (Pirazzoli 1987).

Interglacial situations must have occurred on an average of 100,000 years over at least the last 700,000 years (Pirazzoli 1987). There is a high possibility that these submerged terraces are tectonically elevated and each time the sea level returned, over a period of several millennia, it reached to about the same level as the present one. This caused the shore to be rejuvenated and most of the deposits existing on the coast were reworked or swept away unless the coast had been uplifted. It is only where tectonics have provoked important vertical movements that a series of shorelines has been recorded on the coast. Even, in the best conditions such series are rarely complete as the mark of a shoreline and its conservation depends on several simultaneous conditions such as, among others, exposure, erosion and settlement which hardly remains unchanged for long periods.

Thus the number of recognized Quaternary marine terraces is limited and smaller than those of the Pleistocene. Such sequences are fragmentary and the true levels that can be investigated correspond only to short periods of the Quaternary known for high stands of sea level. It has been estimated from isotopic curves that during the Quaternary sea level might have remained for 75 per cent of the time lower than -20m and for 50 per cent of the time lower than -40 to -50m. (Pirazzoli 1987) This means that even apart from the subsiding shorelines most traces of ancient sea levels are now submerged and most are buried under sediments. However, it has been estimated that in general, during the Holocene, the Mediterranean Sea stood no higher than the present level which has been maintained between 6000 BP and the present.

Since the end of the last glaciation, sea level rose very rapidly. This occurred in the period of 15,000 years. Glacial ice covered the European continent from *ca.* 39,000 to about 20,000 years BP. Since this date, global climates started to warm up, with the result that the glacial ice sheets started to melt, thus draining water into the world oceans and the Mediterranean basin. It has been recorded that 20,000 years ago, global sea levels were at -120 to -100 metres, 15,000 years BP it reached the -70 metre benchmark, 10,000 years BP it was at -40 metres and around 5,000 years ago it reached the present level. Graphs of this eustatic phenomena show a steep and constant acceleration of the process. This is a rapid transgression which affected the Mediterranean coastal zones quite extensively. The marine processes in this transgression had a drastic eroding effect on limestone coasts especially where soft deposits were encountered and exposed.

Variations in the sea level in the Mediterranean depend not only on eustatic, glacio-hydro isostatic, climatic, and rheologic factors existing in the global ocean, but also on well-defined regional characteristics: fragility of the narrow strait connection with the Atlantic Ocean accompanied by an unbalanced water budget, and various tectonic and rheologic processes related to the collision between Africa and Eurasia.

Sea level change in Malta

Rising sea level have also left their imprints on the Maltese limestone coast. Evaluating the Vossabaumer bathymetrical map and the British Navy bathymetrical charts, six bathymetrical sounding points levels are revealed in this exercise. These are the 18m, 36m, 91m, 127m, 145m, 163m, and 182m respectively.

The first question which crops up is the geological composition. The hardest formation is the Lower Coralline Limestone, which takes a long time to erode. Thus, it can be possible that, if there was enough time to cut shore platforms, these would have limited width, though the sea level might have remained stable for quite a long time. However, wider spaced bathymetrical contours indicate that the geological material is much softer. In this case this could be the Globigerina Limestone. Sea levels erode softer limestone much faster than the harder bands. This justifies the reason why these two different bathymetric profiles have difference in the wave-cut benches widths. But this cannot prove all, as there is also tectonism involved.

Gozo has a 4° regional tilt going from NW to SE direction. This changes the morphology of the coastline. Thus, it can be very much possible that the straight narrow intervals between one bathymetrical contour and another can also be due to tectonics and sea level acting together. Most probably such actions occurred in the west of the islands owing to the presence of a high cliff coast, exposed faulted structures and karst features.

Along the northern coast, the stratification beds are inclined, thus enabling the sea level to erode the limestone at an angular phase. Tilting can be the cause of faulting taking place, but not so aggressive, as the limestone only experiences a shearing process. Thus, no large variations in the geology can occur. This indicates that most probably the geology of the submerged central northern coast of Gozo is composed of Globigerina Limestone, one of the softest formations in the islands' rock sequence. An indication of this is the presence of submerged marine terraces, which are exposing a considerable platform width as a result of vigorous marine erosion processes. This can also be seen geographically where the bathymetrical contours are much more widely spaced than those of the west and the southern ones. Following the land geology and the faulting structures, it strongly indicates that the south of the island of Gozo had been subject to intensive tectonic movements. Thus, it is likely that the submerged topography in this section bears imprints of such activity which results in a much steeper profile of the land. Thus, rising sea level produced different landforms along its variations of transgression.

Evidence of sea level rise in Gozo

Rocky coasts are the legacy of marine and sub aerial processes that have been operating for thousands of years. The type, intensity, and focus of these processes have varied with shifts in relative sea level and with temporal and spatial changes in climate, exposure, and rock type. Wave erosion have produced different land forms along shore platforms. Evidence of this lies on a submerged wave cut bench along Xwejni coast in the northern part of the island. Large marine caves, sea arches, and sea stacks are present along this shore platform. Today, these erosional features are preserved as they are submerged, thus not being subject to marine and sub aerial processes.

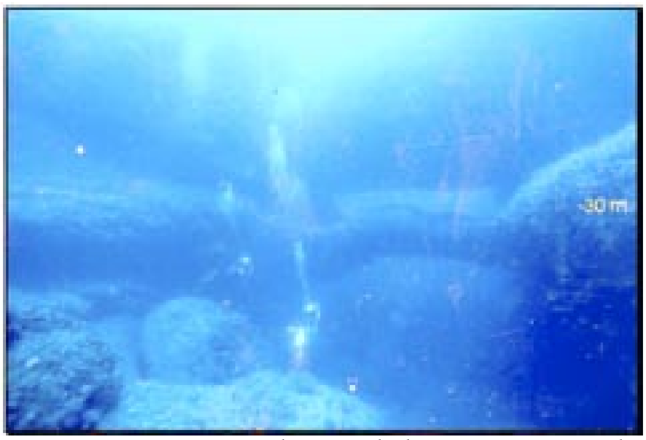

Figure 4: An underwater photograph showing a section of the submerged double arch structure at 30 metres below sea level off Xwejni coast. (Courtesy of Moby Dives)

This submerged coastal section at Qbajjar Bay presents a wide wave-cut shore platform at -15m which extends to about 350m. Small sea arches ranging 8m in width are also present on this ancient shore platform. Such excessive width is due to the long presence of sea level at this bench mark. The Dwejra coastline from the Azure Window up to the Inland Sea cave also presents another wave cut bench at -15m. However, big marine caves extending more than 150m in diameter are also found along the submerged Xwejni coastline at Reqqa Point at -28m. Complementing to this marine erosional structure along this platform lies a spectacular double arch structure. The base of such a sea arch is at -39m while its topmost arch stands at -17m (Figure 4). Such sizeable structure of 19m in height took quite a considerable amount of time to be formed as the composition of this erosional feature is of Lower Coralline Limestone, the hardest limestone band present on the islands, thus offering resistance to marine erosion. The same applies for the marine cave situated at Reqqa Point. Not only the duration of the sea level is important for the sculpture of such physical feature but also the degree of wave erosion.

It has been estimated that the sea level had last been at -36m about 9,000 years ago, when climates were getting warmer, indicating that evidence of violent storms seems lacking in the Mediterranean region. Formations of such large structures are the result of past marine erosional imprints which occurred well before this time.

It took around 500,000 years of wave attack to create such sizeable structures along the coast. The Quaternary was also the time when a drastic change in climates was occurring and a series of cold and warm periods were registered. This had a direct effect on the type of wave attack on the limestone coast which was much vigorous than today and 9,000 years ago. However, the -15m benchmark of past sea levels only display wide wave-cut terraces at Qbajjar, Dwejra, and Ix-Xatt L-Aħmar locations, and smaller sea arches and sea caves. This means that climates were not vigorous, mostly indicating a warmer phase, thus limiting the degree of erosion along the limestone coast. A wide shore platform indicates that sea levels had stood at that specific level for quite a long time. Thus, this also matches Pirazzoli's statement that 75 per cent of the sea level during the Quaternary Period stood lower than -20m.

Such data hypothesize that high sea level stands have less mechanical erosional power than those of lower sea levels. This is due to the climatic variations. High sea levels indicate that climates are warmer, thus it is more likely that solution erosion was acting on the limestone. On the other hand, cold climates indicate the presence of glacial periods. Cold and rough weather frequent wave oscillating power in various degrees to expend their energy on the coast, thus eroding the limestone faster. Such hypothesis can be formulated as the submerged coastline in the west and north-west sections of the island are composed of the Lower Coralline Limestone. Lithological uniformity displaying different scale of marine erosional structures at different sea level benchmark can roughly estimate the type of climate which was acting in the past.

The rise in sea level also submerged valley floors to change their nature to geos. Valleys diminished in size and became natural inlets, some of them protected by headlands, others controlled by their lithology. A particular example is MĐarr ix-Xini valley where the submerged valley floor was filled with sand sediment to become part of the sea bed (Figure 5). This photo illustrates a section of the submerged valley covered with sediment at 10m below sea level. The valley side is a vertical one with an absence of notches indicating a rapid sea level rise which had little effect on the lithology.

Figure 5: A section of the submerged Mġarr ix-Xini valley at 10m below sea level exhibiting vertical wall surfaces of Lower Coralline Limestone and a fine sediment covered sea floor. (Courtesy of Pete & Suzie Millar)

The impacts of sea level rise also left other imprints on the limestone coast. This coastal erosional feature is known as notches. Theseare marks in the limestone face which indicate the presence of sea level. A notch is a laterally extending hollow at the base of the cliff, its width being greater than its depth. The notch roof which is nearly horizontal is termed a visor. Notches are found in resistant limestone bands mostly along the cliffed section of the Gozitan coast. Visible notches at the present sea level only attain 1.5m in size, thus indicating that, during the past 6,000 years, marine erosion was quite limited. Such observations also strengthen the hypothesis that the size and types of shore platforms, and sea caves depend on climatic effects and oscillation of sea level rise. Such erosional features are also present on submerged cliff faces and caves. An example of this are the submerged caves at –25 to –30 metres at San Dimitri Point (Figure 6). This photo illustrates two wave-cut notches which are barely 1 metre apart meaning that most probably the sea level was rapidly fluctuating in the Quaternary Period.

Figure 6: Wave-cut notches situated on the wall surface of a sea cave at San Dimitri Point at 25m below the present sea level. (Courtesy of Pete & Suzie Millar)

All the features discussed account only for the Quaternary Period where no major tectonic movements had occurred, thus making it easier to evaluate rise and fall in sea levels.

From this data, it is confirmed that our shorelines are submerging as climates are getting warmer and sea level is rising. Scientific data shows that:

- by the year 2030 the temperature will increase by 1.4 to 1.6°C and sea level will rise by 12 to 18cm
- by the year 2050 the temperature will increase by 1.8 to 2°C and sea level will rise by 14 to 38cm and
- by the year 2100 the temperature will increase by 1.8 to 2°C and sea level will rise by 35 to 65cm (Sestini *et al* 1992)

The future scenario of the impact of sea and temperature rise on the islands is not promising and it also confirms that our islands are getting smaller as time goes by. This means that our islands are subject to different geomorphological processes which produce different landforms with ever climatic change.

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