Geological and Geomorphological Aspects of the Żebbuġ and Marsalforn Region

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Abstract

The geological history of the Maltese islands is rather a recent one, with its sedimentary formation processes dating back to the Oligocene period. Such sedimentation occurred in shallow marine environments at different sea levels, thus causing the development of the present five geological strata.

However, although landforms occur on a small scale, they were subject to intense tectonic activity. This activity marked the Maltese archipelago with a complex series of faults, which lead to the development of karst geology and geomorphology.

Such phenomena is registered in the formation of the Żebbuġ mesa and Marsalforn valley in northern Gozo. The development of such a striking topographical contrast is rather a complex one as diverse types of geomorphological processes have occurred in the past and have sculptured the landscape as we know it today. Besides this, the area possesses a complex faulting system part of which is submerged. This also aided in the formation and presentation of this region.

This paper examines a brief review of geological and geomorphological processes discussed by various geologists in the past and also argues various hypothetical conclusions conducted by the author through various fieldwork sessions in the area.

Introduction

The Maltese islands are composed of mid-tertiary sedimentary rocks which were formed in shallow marine water environments. Tectonic movements left an imprint on the face of the landscape as the whole archipelago expresses super-imposed phases of strike-slip faulting and rifting with associated up-arching and down warping. Geomorphological processes working on this framework resulted in different types of landforms, though on a small scale in these small islands. This can be seen in the various types of stream channel formation and incision, coastal morphology and formation of erosional surfaces. All these processes have acted vigorously on the Maltese islands in the past five million years since their uplift from beneath the sea and have produced diverse geological and geomorphological features. The Żebbuġ and Marsalforn areas exemplify some of them.

Geology

The Żebbuġ mesa and Marsalforn valley are located in the northern middle section of the small island of Gozo, the second largest island of the Maltese archipelago. The region is composed of marine tertiary sedimentary rocks which date their initiate deposition during the Oligo-Miocene epochs (between 30 to 38 million years ago). This northern section of the island exposes all the geological strata however the Blue Clay and the Upper Globigerina limestone outcrops dominate the area.

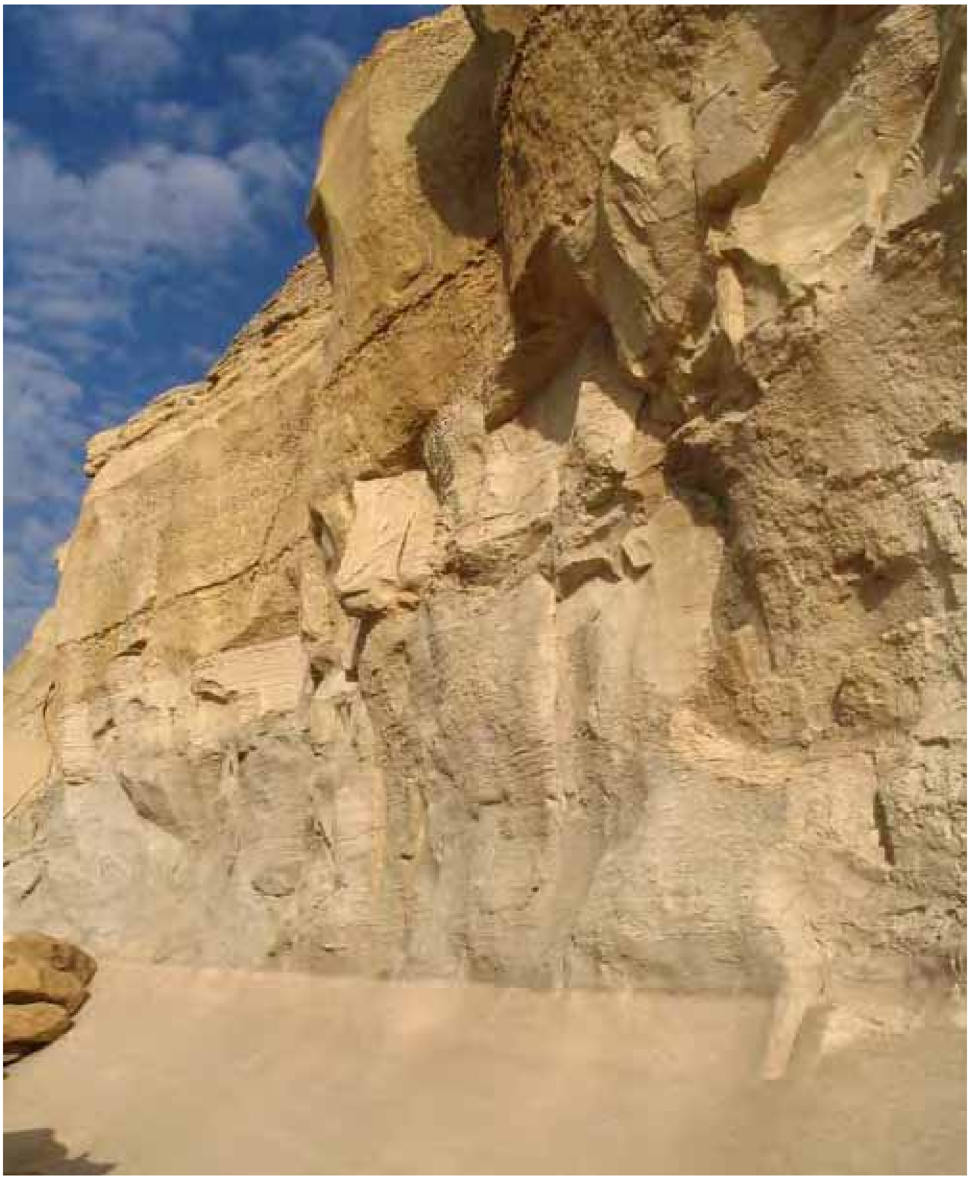
The Żebbuġ plateau top is composed of the Upper Coralline Limestone. This formation is similar in many ways to the Lower Coralline Limestone formation especially in colour and coralline algal content. It consists of pale and brownish grey coarse lime muds and sands containing different species of coralline algae. It is a durable stratum frequently weathering into steep bounding cliffs and bearing well developed karst topography.

Next in sequence is the Blue Clay layer. This is an extremely soft rock which weathers away easily. Its composition consists of pelagic marls with pale beds rich in foraminfera resulting in a medium grey colour. Topographically, clays weather back to 45° slopes and taluses that tend to slide further downhill over the underlying Globigerina Limestone formation. However the Blue Clay is non-porous and rain water slides down to the valley systems.

Most of the Globigerina Limestone found in this area exposed at the surface is of the Upper division of the formation. This geological division is a fine grained soft honeycombed weathering limestone which ranges in colour from orange yellow at the top downwards to a pale grey and then to a creamy yellowish at the base. The base exhibits a ubiquitous phosphorite conglomerate bed containing fish teeth and diverse other macro fossils. This hard bed is termed the Xwejni or C2 conglomerate.

Beneath the Upper Globigerina Limestone at a slightly lower topographic level, the Middle Globigerina Limestone member crops out. This consists of a planktonic foraminifera rich sequence of massive white, soft carbonate mudstones locally passing into pale grey marly mudstones. The base of this formation rests upon the Lower Globigerina Limestone member with a pronounced hard phosphatic bed (the C1 conglomerate series) at the boundary.

The Lower Globigerina Limestone member is a white weathering grey marly limestone which contains numerous nodules (Zammit Maemphel, 1977). Erosion transforms this relatively soft sedimentary bed into a gentle rolling landscape, leaving talus of chocolate coloured phosphatic nodules in various stratigraphical levels as they are much harder to erode. These beds are only a few centimetres thick and the nodules vary



The three divisions of the Globigerina Limestone strata at il-Qolla l-Bajda - Xwejni. [Photo by George Said].

from pea size to ten centimetres in diameter and all contain a high amount of phosphate of lime together with considerable quantities of organic remains often mixed up with casts of shells and corals (Hyde P.T., 1955).

The Lower Coralline Limestone formation is exposed in a very small cliff on the coastline just a few metres off the Għasri valley and in dispersed outcrops embedded in the waterline zone of the Xwejni shore platform. This formation is the hardest limestone on our islands and is composed mainly of shelly debris derived from skeletal remains of calcareous algae, foraminifera and various other shelled organisms which used to live in shallow water. These deposits make up the rocks and beds of large sea urchins, *Scutella subrotunda*, which are exposed on outcrops of Lower Coralline Limestone (Zammit Maemphel, 1977).

The presence of these different geological strata in the region, subject to different erosional processes and the differing resistance of these rocks, controlled the present formation of iż-Żebbuġ as upland and the Marsalforn valley to be eroded down to sea level. In total, these geomorphological processes are quite complex as there are many parameters to be taken into consideration.

Structural and Geomorphological Features

Geomorphological processes in this zone are induced by two main actions, (1) sub-aerial erosion and (2) marine erosion. Sub-aerial erosion includes all those processes which are acting on the land which are directly subject to climatic conditions. Marine erosion consists of all those processes which are triggered by wave action and marine biological activities. However such processes, though different from the previous ones, also depend on climatic actions. Thus climate, and its behavioural patterns, is the principle cause for the triggering of all types of erosion and its rates of processes. The Żebbuġ and Marsalforn regions possess different and distinctive types of erosion and these are depicted in the limestone structures which are unique. The features include:

- Past erosional and depositional features
- Valley formation formed by sequential water drainage actions
- Various mesas
- Marine caves
- Wave cut platforms
- Sea stacks
- Pebble and shingle presence which rest in Marsalforn and Qbajjar inlets

Past Erosional and Depositional Features

When the islands were uplifted to the surface by tectonic forces about five million years ago, they were subject to sub-aerial erosion. The Upper Coralline Limestone bed covered the top of the geological stratification and so this was the first to be subject to erosion. As this geological band is porous, rain water flowed through this rock to initiate solution erosion. This caused caves to be formed at the base of the Upper Coralline stratification.

Distinct from the largely ulithified sediments, cave deposits are formed by crystal growth, usually of calcite, though many other minerals may also be present. Stalactites and stalagmites are familiar examples, the term speleotherms is common and is given to such deposits.

This type of deposition process tends to occur when waters, with calcium and hydrogen carbonate content which are equilibrated with high values of carbon dioxide from the soil and bedrock fissures, encounter the lower values of carbon dioxide present in the cave atmosphere. A disequilibrium situation occurs when percolation water reaches the cave air with the result that the carbon dioxide content of the water drops reaching equilibrium with that of the cave air. Such a situation causes calcite precipitation to occur.

These type of deposits are termed as Travertine deposits. Such deposits are indicated by a crystal rim around a drop of water, the rim enlarging to form a straw of flow stone. Combinations of flow rate, calcium content and local conditions of topography, climate, trace element composition and flood frequency combine to produce a large variety of speleotherm forms.

Thus, Travertine is a denser, banded deposit especially common in limestone caverns where

Wied l-Infern one of the largest valley drainage systems in Gozo. [Photo by George Said].

it forms the well known flow stone and drip stone, including stalactites and stalagmites. Like tufa, it forms relatively small deposits of no great geologic importance and is primarily Quaternary or Recent in age. (E.J., Pettijohn, 1975).

Valley Systems

This northern section of the island of Gozo has several north running valley systems of which Marsalforn valley and Wied l-Infern are two of the largest. These drainage systems which are controlled by faulting trends in the bedrock have cut down to sea level thus exposing the Lower Globigerina limestone strata. However, due to the island's 4° tilt running in a south west to north east direction, water erosion affected these valleys differently. Wied l-Infern is cut in a more steep and narrowish manner. This is because the water flow travels with much faster speed where the topography is high and rushes down to the lower levels. This is indicated clearly from the topographical map where the 30 metre above sea level contour of Wied l-Infern starts from 1.25km inshore from the coast, while that of Marsalforn valley begins 2.5km inshore. Thus, though there is a distance between the two valleys there is a 1.25km of erosional landscape. The reason why Marsalforn valley is much wider than Wied l-Infern is due to the fact that the catchment area of this valley system is by far much larger that that of Wied l-Infern. Thus the drainage flow is much greater in volume as well as rate of flow. However, the steep gradient erosion in these valleys is expressed at different rates. Wied l-Infern possesses a wall gradient of 13° while that of Marsalforn valley is 8°. This clearly means that water in Wied l-Infern rushes seaward much faster than water in the Marsalforn valley. This leads to different geomorphological processes. Water rushing through the Wied l-Infern valley erodes less material due to the lower volume of water it is subject to as against the large volume of water which drains through the Marsalforn valley.

So the valley systems which are running on the left side of the Żebbuġ mesa possess different properties though the environment is a micro one. In fact this leads to the formation of isolated roundish mesa limestone features on this particular side of Żebbuġ.

Mesa Limestone Features

Sub-aerial erosional processes have produced several conical shaped hills. These are known as 'Is-Salvatur', 'Il-Qolla s-Safra' and 'Il-Qolla l-Bajda'. These structures are presented in this particular way due to the pattern of the erosive actions which have acted on the island for the past five million years. Such particular shapes are due to the resistance properties of the limestone.

The softest geological material is Blue Clay, followed by Green Sand and the Globigerina Limestone, while the hardest is the Lower Coralline Limestone, seconded by the Upper Coralline Limestone. The Upper Coralline Limestone tops the geological succession of the island. It is a resistant rock which is not so easily eroded but it is porous. Water infiltrates through this rock mostly through its faulted planes to find its way to the Green Sand and Blue Clay layers. As these are the softest bands of the geological stratification, weathering away of these materials occurs at a much faster rate. This results in the expansion of the Blue Clay layer, as it is a non-porous rock, with the result that it causes structural weakness in the Upper Coralline Limestone band. Such action caused this top geological strata to develop cracks large enough to initiate the toppling of sizable limestone blocks to slide down along the valley systems and end up at sea. In the meantime the three Globigerina limestone bands were also eroded by the water action. They were eroded in a stepped manner depending on the resistance of the bed. In this case the Lower Globigerina limestone member is the most eroded, followed by the Middle and Upper bands. So these rounded cone like structures exhibit all the bands of the geological formation. The difference is the volume of rock. Millions of years ago they were one whole uniform block but sub-aerial erosion processes have caused the development of pinnacle structures.

Marine Caves and Wave Cut Platforms

Coasts are subject to inputs of both marine and sub-aerial energy and materials which interact with the geological work to produce coastal landforms. The energy inputs are mainly provided by waves. One of these coastal features is the shore platform. These are mostly found in tectonically uplifted coasts where erosion is active and have a topography of prominent cliffs and headlands that jut out into the sea alternating with narrow inlets and irregular bays, some filled with small roundish pebbles and shingle material.

The degree of wave erosion and the hardness of the rock are two features which determine the development of the shore platform along the Xwejni coast and on the western side of

The rugged solution pool surface of the Marsalforn shore platform. [Photo by George Said].

The Xwejni Shore platform exhibiting a 4º dip. [Photo by George Said].

Marsalforn bay. The wind factor is also important as it is the agent which triggers the development of waves far out at sea. The north westerly wind (Majjistral) is the prevailing wind on the islands and thus the rocky shore at this coastal zone is subject to heavy wave forces acting on it. Such vigorous action is the cause of extensive erosion of the Globigerina Limestone, which is the dominant outcrop of this rocky shoreline. As this type of rock is a very soft limestone, erosion rates are quite high. This can be determined from the concave smoothness and the flaky face of the Upper and Middle Globigerina strata, which form the cliff face of the shore platform.

The retreat of the cliff face by marine erosion brought to prominence the seam of phosphatic nodules, chocolate brown in colour that is the separating agent between the Upper and the Middle Globigerina layer. Phosphatic nodules have different geological compositions and are much harder than Globigerina Limestone, thus being less erodable. This caused the area to be eroded in a stepped form manner as the C1 and C2 Phosphate Conglomerate beds are controlling the marine erosional processes due to their resistance composition features. As the surface of the Lower Globigerina strata is composed of the C2 Phosphate Conglomerate bed which is very hard to erode, it protects the limestone to a certain extent to allow marine erosion to cut this foraminifera bed in a narrow wave cut bench known as a shore platform.

The Middle and Upper Globigerina are much softer bands and their retreat landwards is due to wind, rain, wave and sea spray action eroding above the shore. Where the wave action is constant and regular the vertical face of this shore platform is a concave, smooth slope. This degree of smoothness is also present on the Middle Globigerina wall, where erosion has exposed the phosphate conglomerate bed in a jutting manner thus to form the visor of the concave face section. Had there been the absence of such hard beds, the area would have been eroded in a smooth concave manner as the limestone texture is a soft one, thus leading to a different development of shore platform.

The rough surfaces present in various sections of the Xwejni and Marsalforn shore platforms are not only due to the presence of phosphatic nodules, but also due to different marine erosional features acting on the platform itself. The erosional processes on the shore platform are in the form of solution pools. These are shallow flat bottomed depressions cut in calcareous rock. Solution pools develop from small pits or holes with diameters ranging from a few millimetres to a few centimetres due essentially to biochemical processes which are characterised by the removal of the disintegrated rock material by waves and grazing organisms. The pools extend laterally in all directions from the original depression keeping rough circular outlines and their depth varies according to the intensity of erosion on the shore platform. As you go towards the shoreline, the deeper and more irregular the solution pools are. However due to the hardness of the phosphatic nodule layers, the development of solution pools is not so abundant. In fact we find that substantial parts of the Marsalforn and Xwejni shore platforms are very rugged, while diverse small sections are not so clustered with nodules and thus it is much smoother than the rest.

However, as the Xwejni coast position is more exposed to the wave forces than the Marsalforn inlet, the shore platform in the area has some distinct features. The western section of this shore platform includes a cave feature cut into the Lower Coralline Limestone. Caves are cut at sea level and along lines of weakness. Adjacent to this cave lies a very small shore platform which drops down to sea level. The floor of this wave cut bench is composed of Lower Coralline Limestone, while the wall is formed of Lower Globigerina Limestone. Such feature is present due to the wave quarrying of the Lower Globigerina Limestone wall, thus exposing the surface of the bottom geological feature, that is Lower Coralline Limestone. A similar but a slightly larger wave cut bench is present a few metres from the first one. This bench is cut across the surface of the Lower Coralline Limestone. Another small micro shore platform is cut in the Lower Globigerina Limestone. The different surfaces of these shore platforms result from the solution erosion acting on the surface. All three micro shore platforms possess solution pools, but they differ according to the geological texture of the limestone concerned. Solution erosion on the Lower Coralline surface is presented in the form of a pinnacled surface while in Globigerina Limestone we have smooth rounded pans. One common thing between these two aspects is that the pans have a flat base.

Solution pools are presented in an irregular manner at the eastern section of the coastal zone as this tip of the shore platform slopes down to sea level. The depth of the solution pools is greater, though they are partly composed of phosphatic nodule beds. Thus this coastal section shows different types of solution pool erosion. The major differences result from lithological composition and the land elevation. Where the solution pools are present in the Globigerina Limestone and elevated a few metres above sea level, their form is smooth and roundish. But when they are at sea level they develop an irregular form as the circular depressions overlap each other. Solution erosion in Lower Coralline Limestone is different. As the material is much harder to erode, it does not smoothen itself but it is presented in a rough angular form.

Another aspect of marine erosion is that it is more vigorous at the eastern section of this shore platform because it is close to sea level, thus waves are continuously breaking and rolling over this limestone pavement. Such action covers part of the platform with rounded and well polished pebbles of various sizes. This is a high energy zone as the wave power breaking on this section of the shore platform is scouring the pebbles along the submerged part of the platform. This section of the coastline is in a shallow step form manner, slightly lower than the present exposed surface. The area presents various grades of rounded pebbles. In fact there is fine grained sand followed by medium rounded pebbles at the back shore of the area.

Thus the marine action at the eastern end of this platform is presently much more active than that at the western end due to the lower elevation of the land surface.

Tectonism has a direct contribution to the formation of the Marsalforn and Xwejni coastal sections. This is imprinted in the stratification of the limestone beds as the strata depict a dip of 4º in a west to east direction. This is shown clearly on the Xwejni shore platform, where the western section is higher than the eastern part. In fact the western part is 7.5 metres above sea level and it presents a cave in the face of the Lower Coralline Limestone wall while the eastern section is down to sea level. Faults do not seem to be present on the land surface but from the shape of the coast it might indicate that normal faults may be present in the shallow sea zone of the area but this is only a hypothesis.

The area is undergoing various geomorphological processes. Here such processes are not too complex. Soil creep is moving debris towards the coast as the agricultural fields are supported by the Blue Clay layer which moves according to the climatic change.

Another geomorphological feature is the toppling of small limestone blocks off the Middle Globigerina Limestone face. This process is in the form of flaking as the rain water slides on the Blue Clay layer, thus rolling across the Globigerina shore platform to end up in the sea. Limestone blocks have also toppled near the circular structure known as il-Qolla l-Bajda. Here we find sizeable limestone boulders scattered on the shore platform in the eastern section of the area. Such processes indicate that the zone is not that active in toppling and creeping action. On the contrary it is affected mostly by marine erosion processes.

On the other hand the Marsalforn inlet expresses an interesting geomorphological feature. This is a sea stack situated at the tip of the eastern part of

Boulder toppling process at il-Qolla l-Bajda. [Photo by George Said].

the inlet. The development of a sea stack evolves through the creation of a sea arch. This happens where waves attack either one or both sides of a promontory and succeed in tunnelling a hollow completely through it. This formation is usually associated with geological weakness and hence a collapse of the vault of the arch occurs due to the action of waves, wind and sea spray which finally leads to the formation of an isolated limestone block labelled as a stack. The degree of such an erosional feature depends on the resistance of the rock. In this case, as this coastal section is composed of the Lower Globigerina band, the rock is soft and thus its erosional rates are high. In fact old photos of this area show that once a sea arch was present and today we are left with an isolated limestone block. This clearly means that geomorphological processes are still active.

Marsalforn is also subject to a high wave energy environment. This is due to the presence of the roundish pebbles which are present in the middle of the inlet. The degree of roundness and smoothness of the pebbles indicates that vigorous abrasion processes are taking place. This results in high erosion rates for this coastal zone.

Conclusions

All these different geomorphological processes which have been acting in such a small region since the late Miocene, have created diverse exposures of various geological structures in the Maltese islands. The presence of such valley systems together with cone structures indicate that past sub-aerial processes were quite dynamic. However, with no exception, this also applies to the marine processes which are also vigorous and lead to the formation of shore platforms exposing solution erosional features in the form of flat rounded depressions. Cave and stack formation also indicate that such erosional processes are continuous and highly effective as they have the power to change landscapes over various time scales.

This calls for environmental concern for the Żebbuġ mesa and Marsalforn Bay so as to preserve their natural environment as it is continuously changing by natural physical processes as explained and also nowadays by diverse actions of mankind.

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