Unit 4 – Karst Heritage

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Preamble

In this unit, we examine the relation between hydrological processes, the geology of karst rock and the resultant landforms. While being described as 'unusual', the landforms may take such dramatic proportions that they merit the designation of a World Heritage Conservations Site. The Qawra/Dwejra area in Gozo is presented as a case study.

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> and incision of steep-sided valleys to be found in the Maltese Islands occur here"
>
> (Cassar et al, 2004) on the Qawra/Dwejra area in Gozo

Karst Landscapes

Karst landscapes or terrains represent a distinctive topography in which the landscape is largely shaped by the dissolving action of water on carbonate bedrock. This geological process, occurring over many thousands of years, results in unusual surface and subsurface features ranging from sinkholes, dolines, vertical shafts, disappearing streams and springs, to complex underground drainage systems and caves. The 'engine' that powers this natural process is the hydrological cycle, starting with the constant flow of rainfall over the rock surface which causes the chemical dissolution of the rock along fissures. Over time, these fissures gradually enlarge into veritable shafts and conduits, which allow a larger part of the rainwater to feed into the aquifers within a shorter period of time. The circulation of meteoric waters underground actively continues the dissolution process of the bedrock. The conduits enlarge into caves and, in those instances where the ceiling of a cave eventually collapses, a so-called sinkhole is formed.

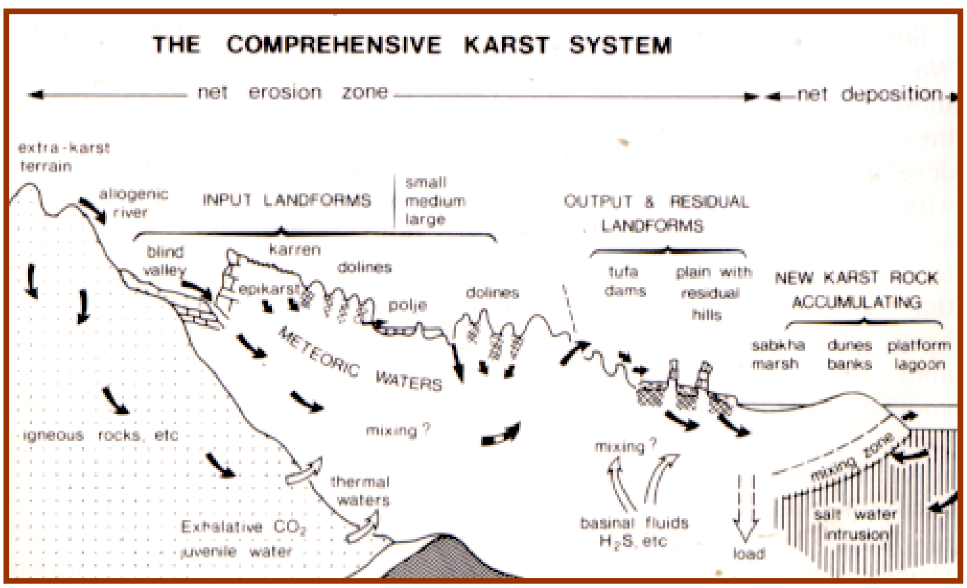
In well-developed karst terrains the most important drainage system lies underground – a subterranean river system. The soluble rock undergoes karst "plumbing" by the water seeping underground. The solution processes resulting from the percolation of rainwater through the porous limestone rock create an underground network of conduits and caves. The dissolution of the limestone is dependent on the acidity of the water in contact with the rock. The greater the quantity of carbon dioxide in the water the more acidic it is. Rainwater is a weak solvent because it has low carbon dioxide and therefore low acidity. However, water leaching through soil may contain much higher levels of carbon dioxide, as well as other acids, and is more effective at dissolution.

Considerable rock solubility alone is not sufficient to produce karst. In fact, soluble rocks with extremely high primary porosity usually have poorly developed karst. The development of karst requires fissures and therefore pathways to be created within the solid matrix of the rock. The latter openings define the so-called secondary porosity of the rock. This explains why soluble rocks with negligible primary porosity that have later evolved a very large secondary porosity support excellent karst. Ford (1989) emphasizes that 'The distinctive landforms both above and below ground that are a hallmark of karst result from solution along pathways provided by the rock structure'.

Ford identifies a number of key points in understanding the relation between hydrological processes, the geology (of karst rock) and the resultant landforms:

- **hydrological processes** determine the general location of erosion and hence are usually the **principal control on landform development**. In particular, the nature of hydrological recharge, whether autogenic, allogenic or mixed, has considerable morphological significance because of its influence on the horizontal and vertical distribution of the solute pathways.
- **geology influences karst development** through its control of (i) the provision of solute pathways (ii) rock strength; and (iii) susceptibility to corrosion.
- different amounts of runoff in various humid regions influence annual karst erosion and hence the rate of landscape evolution, but **not necessarily the morphological style** of karst topography that is developed

Thus, Ford provides a schematic diagram illustrating the major phenomena encountered in active karst terrains.



Reproduced from Karst Geomorphology and Hydrology (Ford & Williams, 1989)

Karst in the Maltese Islands

The Maltese Islands are characterised by well-developed karst phenomena which result in truly dramatic landforms. Several dolines as well as many caves (Calypso's cave in Gozo being the most legendary) can be found in the uppermost geological layer, the Upper Coralline limestone. The Lower Coralline hosts archaeologically important caves, sinkholes (il-Maqluba, Malta) as well as some spectacular natural arches (Azure Window in Gozo, Blue Grotto in Malta). Inland, this rock type forms barren, karstified limestone platforms (Ta' Ċenċ, Gozo).

Far less karstified compared to the previous limestone formations, karstic channeling and cavities are found mostly where the Globigerina outcrops. Being used as the favoured building stone, atmospheric weathering of the Globigerina limestone results in its typical honeycomb features that add an equally dramatic touch to facades and bastions (defence walls built during the times of the Knights of Malta).

The sinkhole found at il-Maqluba (Malta) merits special attention as it is an important example of how the mixing of seawater and freshwater may accelerate the dissolution of the carbonate rock. The water catchment is restricted a small radius around the sinkhole, and hence natural runoff alone cannot logically explain its impressive size. In all probability, the bottom part of the sinkhole is in direct communication with seawater along one or more underground conduits running below the valley known as Wied Babu. The Blue Grotto is found at the exit of this valley and can be accessed from the sea by boat. This cave also coincides with the location of a temperature anomaly in the seawater.

It is logical to assume that the same conduits can also serve to bring substantial amounts of seawater inland, e.g. during stormy periods. Furthermore, one could make the hypothesis that the conduits were created and/or substantially enlarged during periods when the (mean) sea level was higher than it is today. With this understanding, an inland cave enlarged up to the point where the ceiling collapsed and a truly impressive 'vertical shaft' or sinkhole was formed.

Thermographic Surveys to detect freshwater outflows into the sea

Airborne thermographic surveys provide a means to detect 'anomalies' in the surface temperature along a coastline. The anomaly arises from the fact that freshwater is draining into the sea in a sufficient quantity to allow for a difference in temperature between freshwater and seawater to be observed.

Although the difference between the (cooler) fresh water and the (warmer) seawater is commonly at its highest towards the end of the summer season, thermographic surveys have yielded more conclusive evidence when these were carried out in the wake of rainy conditions. The freshwater outflow into the sea at the end of summer (i.e. after 2 or 3 months without rainfall) is too low in quantity for the anomaly to be picked up by thermal infrared imaging.

To date, thermographic surveys around the coastline of the Maltese Islands have not yielded any evidence of large, submarine springs, but have confirmed that in certain locations (including Blue Grotto), there is a marked concentration of groundwater draining into the sea.

Tal-Maqluba Legend

Not everyone agrees on the karstic origin of the sinkhole. In fact, according to legend its origin is of a quite different nature. This legend recounts that where today lies the area known as “tal-Maqluba”, just south of the village of Qrendi in Malta, there was a village inhabited by very wicked people.

They were so evil that God punished them by opening the ground, 50 metres wide and 40 metres deep, and the whole village was swallowed by the earth! The opening in the ground stopped exactly in front of a chapel, which is still present just by the edge of this enormous hole.

One assumes that only those who happened to be inside the chapel were spared from this calamity.

Fieldtrip at Maqluba Sinkhole

Valleys

Today, similar to Malta, Gozo is a semi-arid island, where seasonal flash floods produce the occasional stream or river flows. Most of the river valleys in Malta and Gozo are considered dry valleys. Dry valleys usually refer to valleys found in karst terrains that no longer have a surface flow of water. In an arid or semi-arid karst environment the limited surface runoff is usually completely absorbed underground by the permeable limestone. In well-developed karst environments, as in Gozo, where permeability is high, surface water tends to run below the streamcourse in underground cavities and solution channels.

A karstified drainage system can also lead to the development of blind or disappearing streams. A typical example of a blind valley is found at Ħondoq ir-Rummien, in the south-eastern part of Gozo.

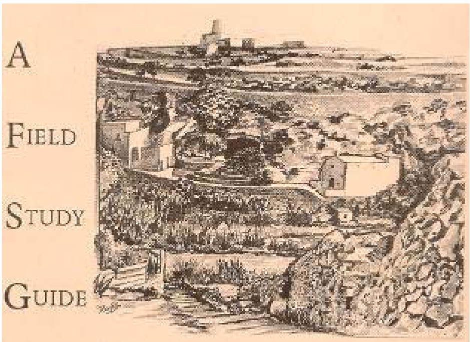
During more pluvial times, the runoff collected in streams and rivers was much higher, scoring deep incisions into the landscape, particularly in those areas where the softer Globigerina Limestone is found at the surface. Typical examples of this process are found in the north-eastern part of Gozo (Wied ir-Raħeb, Wied il-Mielaħ and Wied Għasri), where the successive members of the Globigerina Limestone were eroded and the underlying Lower Coralline Limestone is exposed in the valley bed.

Mgarr ix-Xini, an example of a gorge-shaped valley formed during pluvial periods

Valleys (*Widien*)

Valleys are drainage channels formed either by stream erosion during a previous (Pleistocene) much wetter climatic regime, or by tectonism, or by a combination of the two processes. Most ***widien*** in the Maltese Islands are now dry valleys, that is, they only carry water along their watercourses during the wet season; a few ***widien*** drain perennial springs and have some water flowing through them throughout the year, attaining the character of miniature river valleys. By virtue of the shelter provided by their sides and their water supply, ***widien*** are one of the richest habitats on the islands; they are also extensively cultivated. (Schembri, 1993)

Let's go to Wied il_Lunzjata, A Field Study Guide (Haslam S. and J. Borg, 2001)



Wied Lunzjata is undoubtedly one of the most picturesque valleys in Gozo. Used by the Knights of Malta as a hunting area, Lunzjata Valley continues to be a very important area for agriculture today. Visitors are treated to the sound of continuously running water from the many springs and in the traditional irrigation channels (made up of rectangular blocks of stone) and (miniature) aquaducts. This Field Study Guide allows today's visitors to explore both the natural and built heritage features of this 'jewel of Gozo' in a truly fun, yet very comprehensive manner.

Caves

The term cave (***għar;*** (pl) ***għerien***) usually refers to passages or chambers that are large enough for human entry. Unusual formations called speleothems represent a common feature inside karstic caves. These are carbonate/mineral deposits that are usually formed, over millions of years, by the slow action of water seeping through small fissures. Speleothems hanging from the ceiling of the cave are called *stalactites*, and those growing upwards from the ground are referred to as *stalagmites*. The presence and concentration of speleothems is also dependent on the presence of carbon dioxide or acidity of the water.

Caves also provide important archaeological and palaeontological environments. Due to their conductive nature, caves function as sediment traps, accumulating richly varied deposits.

The better known caves in Gozo include Calypso's Cave, Xerri's Grotto, Ninu's Cave and Għar Ilma. The former three caves are situated within the boundaries of the Xagħra Local Council. Calypso's Cave may not be considered an impressive cave in terms of karst features, but its association with Homer's epic "The Odyssey" always manages to generate curiosity among visitors to the island. In Homer's epic poem, The Odyssey, Calypso keeps the Greek hero Odysseus as a prisoner of love for 7 long years. Xerri's Grotto and Ninu's Cave, on the other hand, provide some remarkable natural speleothems, of both stalactite and stalagmite formations. In Xerri's Grotto there are also some interesting formations, which have developed as the result of calcification of tree roots. In Ninu's Cave, the calcification of water dripping from the cave ceiling formed numerous magnificent columns standing side by side. Għar Ilma provides an example of an important archaeological site due the deposits that were found suggesting its use as a dwelling during Neolithic times.

The Gozo coastline is also dotted with a large number of seacaves. It is quite likely that some of these caves started as inland karst forms, i.e. underground caves which were later invaded by seawater. From this point onwards, the wave action became the dominant agent for the continued erosion. The mechanical action of seawaves and the receding cliffs have at times provoked the collapse of the ceiling of the caves of karstic origin, as seen in the circular subsidence structures found on the coastline at Dwejra.

Seacaves are found all along the western coastline of Gozo

An impressive example of the action of seawaves on karstic coastal caves is the spectacular limestone archway found at Dwejra Point, referred to as the Azure Window. This is a natural arch rather than a window and was formed by the enlargement of an initial cave that developed along a line of rock weakness, which has cut through the limestone, resulting in the arch being formed. The long ledge of rock forming the upper arch is in danger of collapsing and ultimately the roof will fall down and the westerly remnant will form a stack, similar to Fungus rock.

Azure Window at Dwejra

It should be borne in mind, however, that the seacaves we see along the coastline today, are the result of the most recent karstification only, i.e. the karstification process controlled by the present sea level. Prior to the melting of the ice-sheets in the Northern hemisphere seawater levels were at least 100 to 125 metres lower than today (Yevyevich, 1976), hence the sea must have submerged previous karst systems. Previous springs became submarine springs, while conversely seawater invaded karst systems, which explains the often very complex properties of coastal karstified carbonate rocks.

Solution Subsidence Structures

Subsidence structure is the general term used for the different types of natural depressions occurring in karst environments, which are also referred to as dolines and sinkholes. The formation of these structures can be varied, but it is mainly associated with the solution of limestone by percolating acidified ground water which eventually leads to roof collapse of the enlarged underground caverns or caves. These structures can range from a few metres to a few hundreds of metres in diameter and in depth, and they may occur as isolated features (as for example the Maqluba sinkhole in Malta), or in groups as for example in the Qawra area in Gozo.

There are several subsidence structures distributed throughout the island of Gozo, including in Xagħra, in Xlendi, at Wardija Point, and in the San Dimitri area. Further inland, structures can be seen in the Dbiegi area and also under the foundations of the Ċittadella in Rabat (Victoria). The most important are those found in the Qawra area. Here, both the Inland Sea and Dwejra Bay provide excellent examples of large-scale circular subsidence structures that were formed during the Miocene period.

Dwejra Bay

Inland Sea

Fungus Rock, or ***il-Ġebla tal-Ġeneral*** as it is locally known, is another karst feature of note in the area. It is found several metres away from the shore and is the surviving seaward edge of a collapsed subsidence structure. This outcrop, or stack, is surrounded by spectacular sheer vertical cliffs and is home to the rare phallic-shaped Fungus Melitensis *(cynomorium coccineum)* Despite its many given names referring to it as a fungus, the plant is neither a fungus nor is it found only in Malta or Gozo. The Knights of St. John believed this plant to possess medicinal powers and went to great extremes to guard the Fungus Rock and protect the much prized plant. Anyone caught stealing the plant was sentenced to death or put to the galleys.

Other karst features

Other features in the karst landscape of Gozo include grikes and clints, as well as a dense development of solution pits and solution pans.

Typical grike and clint topography

Grike-and-clint topographies are common in karst landscapes and are an assemblage of irregular, deep, narrow grooves present at the rock surface, also known as 'limestone pavement'. These forms are referred to as 'Karren' (German) or 'Lapies' (French). On sea coasts, the biochemical activity of marine organisms present on the rock surface is an important contributor to the development and morphology of coastal karren.

Solution pits are round bottomed erosion pits that are usually circular, elliptical or irregular.

Solution pits at Dwejra

Salt pans at Marsalforn

Solution pans, on the other hand, display a flat or nearly flat bottom that is usually horizontal. In the past, these solution pans were sculpted into a more regular arrangement by man and used as salt pans. An example of such salt pans, which are still in use to date, can be seen at Marsalforn.

Qawra/Dwejra: A world heritage site of karstic origin

Some of the most captivating landscapes in the world are karst landscapes. The spectacular and intriguing formations that result from the development of such landscapes provide unique scenery of exceptional beauty. "The importance of conserving representative karst areas for science and recreation has been recognized in many countries by the designation of national parks and reserves" (Ford et al., 1989).

The Qawra/Dwejra area in Gozo is a case in point. Located on the western coast of Gozo, the area has been identified as an area of international scientific and aesthetic importance. It is a typical karstic terrain offering a dramatic landscape dominated by impressive sheer limestone cliffs and a series of large subsidence structures as well as numerous examples of coastal erosion features and dry river valleys.

The importance of the area was emphasized in the Malta Structure Plan (1990), which identified the area as having "potential international scientific importance because of the complex of features of geological, geomorphological, ecological, archaeological, historical and aesthetic interest".

In 1993, the area including the Dwejra coastline, Fungus Rock and the Inland Sea were declared a 'Nature Reserve', a designation which was changed into a 'Bird Sanctuary' in 2003. Meanwhile, in 1998 the Government included the Qawra/Dwejra area in Malta's potential list of UNESCO World Heritage sites. Dwejra is also protected on a local and international level as part of the EU's Natura 2000 network.

Qawra/Dwejra Heritage Park

In 2005, the Malta Environment and Planning Authority and Nature Trust (Malta) issued the Qawra/Dwejra Heritage Park Action Plan. "The aims of the Park are not merely conservation-related but also include the fulfillment of educational goals and the provision of opportunities for activities such as agriculture and eco-tourism".
(Dwejra Heritage Park website, http://www.dwejra.org/)

As mentioned earlier, the area hosts excellent examples of large-scale circular subsidence structures dating from the Miocene period (Inland Sea and Dwejra Bay) as well as a number of important coastal erosional features such as sea caves, natural arches (Azure Window), stacks (Fungus Rock) and reefs. A report commissioned by Nature Trust (Malta) on the terrestrial ecological resources of the Qawra/Dwejra confirms that “Some of the best examples of normal faulting, karstification and solution subsidence, cliff recession, cave formation as a result of marine erosion, and incision of steep-sided valleys to be found in the Maltese Islands occur here” (Cassar et al, 2004).

The area contains important natural habitats, such as freshwater pools and saline marshes, typical of the Maltese Islands. These fragile habitats are host to a large number of endemic, rare and endangered species. Furthermore, the area’s archaeological significance is traced back over more than 7000 years, from the first known Neolithic culture in the Maltese Islands to the Temple Period (4200-2500 BC) as well as evidence of human activity during the Bronze Age.

Thematic Map and Information Layers for Unit 4

The Thematic Map associated with Unit 4 in the WebGIS is made up of the following information layers:

Gozo Coastline: segment map showing an outline of the coastline of Gozo

Gozo Gorges: polygon map showing the distribution of gorges in Gozo

Gozo Dolines: polygon map showing the distribution of solution subsidence structures (dolines) on the island

Gozo Inland Sea: polygon map delineating the area of the Inland Sea

Gozo Water Courses: segment map outlining the main water courses in Gozo

Gozo Caves: point map showing the distribution of caves in Gozo

Gozo ValleyNames: point map giving the names of the main water courses in Gozo

Layers	Type	Visible	Selectable	Attribute data (short name)	Attribute data (description in full)
Gozo Coastline	Segment	Yes	Yes		
Gozo Gorges	Polygon	Yes	Yes		
Gozo Dolines	Polygon	Yes	Yes		
Gozo Inland Sea	Polygon	Yes	Yes		
Gozo Water Courses	Segment	Yes	Yes		
Gozo Caves	Point	Yes + show labels	Yes		
Gozo ValleyNames	Point	Yes + show labels	Yes		

Useful Weblinks

http://www.conservationgis.org/cave/cave.html
http://www.doc.govt.nz/upload/documents/science-and-technical/SFC198.pdf
http://www.dwejra.org/
http://www.gsi.ie/Programmes/Groundwater/Karst+Booklet
http://www.karstconservancy.org/
http://www.limestone-pavements.org.uk/geology.html
http://www.showcaves.com/english/mt/karst/index.html
http://www.speleogenesis.info/
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