



# Coastal Geomorphology in Practice

## A Case Study: Xrobb l-Ghagin

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Degree of Bachelor or Arts (Honours) in GEOGRAPHY

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*Dedicated to*

*Salvatore*

*Thank you for your encouragement and continuous support.*

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# **ABSTRACT**

This dissertation will present a general overview of the geology and coastal geomorphology of the Maltese Islands. This will be followed by a brief study of literature available discussing these fields. This will serve as an introduction to the area of study: The Xrobb L-Ghagin Area.

Through the observation of past maps, aerial photographs, ground based photographs and a number of field visits; a geological and a geomorphological map will be created. The main focus of this dissertation will be coastal geomorphology and consequently the geomorphological map will be created with much greater detail followed by an explanation and classification of each geomorphological formation. Furthermore, the main erosional factors which create such structures will also be discussed.

The idea for this dissertation started with a realization of the lack of study and perhaps interest in the field of geomorphology. The need for a geomorphological map of the whole of the Maltese Islands stirred up a desire to be part in contributing one of the first studies in achieving this objective.

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# **Chapter 1**

## **INTRODUCTION**

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## 1.1 Overview and Aim of Study

The coast can be considered as one of the most important natural resources of the Maltese Islands. It has been a crucial aspect in the social and economic development of the islands. Geomorphological research on the Maltese coast, however, has been and still is very limited with the result that coastal development has often brought about coastal degradation due to the lack of considerations made to the damage that might be caused by the development itself. The aim of this study is to contribute to the geomorphological knowledge of rocky coasts by mapping and assessing geomorphological aspects of the Upper Globigerina Limestone formations at Xrobb l-Ghagin.

The study deals with coastal geomorphology and is mainly the result of research based on several fieldwork sessions. It tackles and tries to investigate in detail, particular features and maps them on a geomorphological map, keeping a particular focus on Xrobb l-Ghagin.

Having a particular interest in geomorphology and recognizing the lack of study in this field, predominantly in the southern zone of Malta, I chose this area for investigation. The works of Paskoff and Sanlaville (1978) and Ellenberg (1983) have been the first studies dealing with the coastal geomorphology of the Maltese Islands. These however, have made use of the broad-brush approach and considered a large number of coastal geomorphological feature of the islands as a whole. Detailed studies of each particular feature mentioned are still to be undertaken.

The introduction consists of a description of the field site, an explanation of the aims and objectives of the research, an outline of the contributions to the study of coastal geomorphology of the Maltese Islands, and a brief overview of the structure of this dissertation.

## **1.2 Description of Field Site**

Xrobb l-Ghagin is located in the south eastern part of Malta and forms part of the Delimara peninsula between the town of Marsascala and Marsaxlokk. The only people who attend this location regularly are farmers, hunters and divers. This area is in fact known as one of the best diving sites in Malta. This is because 800 metres off Xrobb l-Ghagin at a depth of 42 metres, a plane crashed into the water and is the focus of numerous diving expeditions. During the summer season it is visited by both tourists and local people for recreational purposes, namely swimming, sunbathing and diving.

Entry into the water on the South Western is gradually sloping from shallow into the deep water while the North Eastern side of Xrobb l-Ghagin has a reef characterized by a sharp drop to about 12 metres in depth. On the Southern tip a rocky slope covered in weed, drops to 10 metres. The bottom beyond is sandy with posidonia meadow patches gradually dropping in a South Easterly direction. On the South Western side of the peninsula in an approximate distance of 50 metres from the bay a small island is located island surrounded by 3 to 6 metres deep water.

Right at the top of the cliffs at Xrobb l-Ghagin is a built-up area covering 155,950m<sup>2</sup> which used to be the “Deutsche Welle” Radio Station. This closed down in 1996 and has remained unused until now. It is bounded by a high perimeter wall except on the Northern side which is open to the sea cliffs in the area making the site inaccessible. After the closing

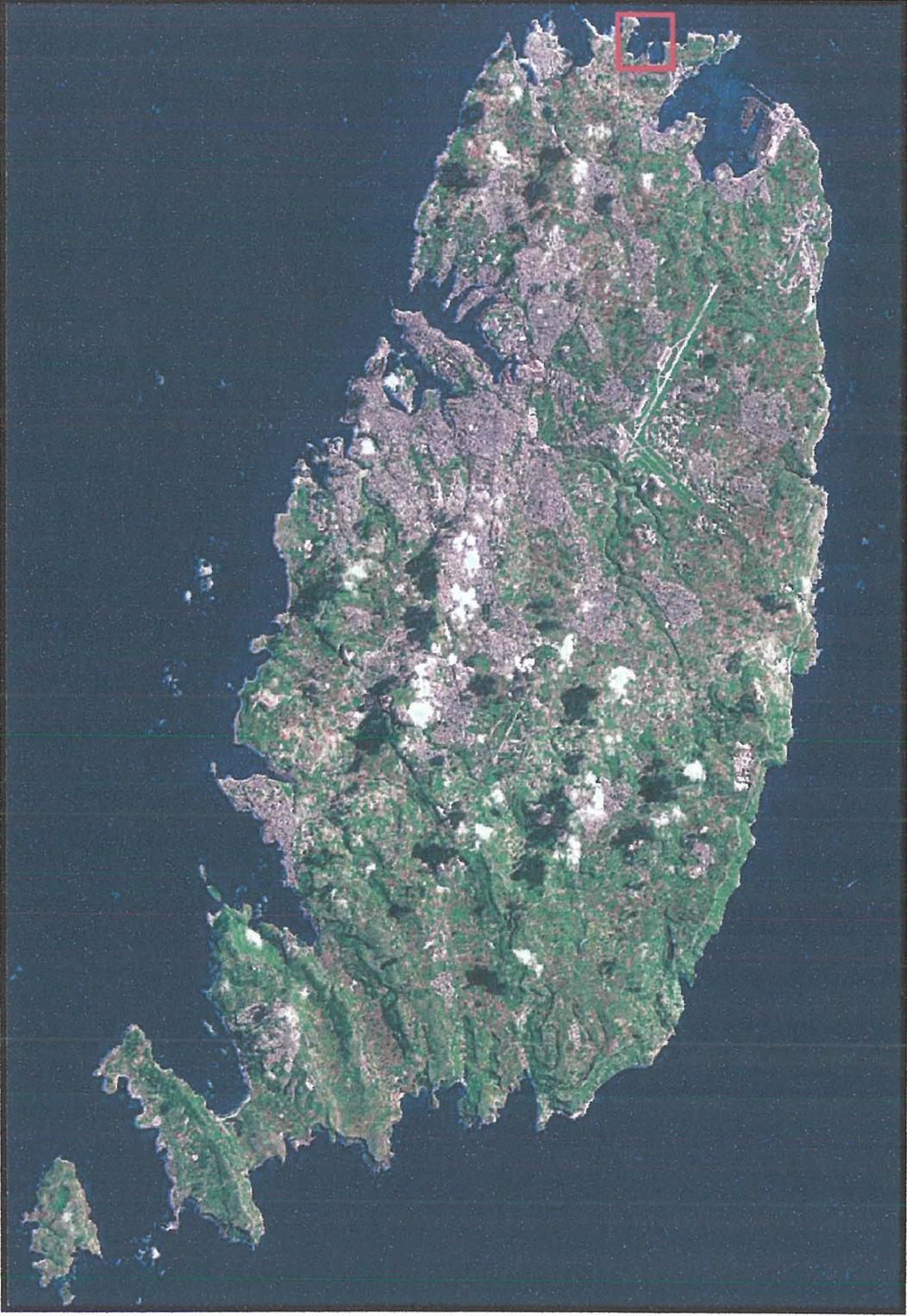
down of this station, the coastal area was taken under the hands of Nature Trust, the Ministry of Rural Affairs and the Environment, and the Faculty of Engineering and the Department of Physics of the University of Malta as a site for conducting their environmental research. It is protected as a scheduled area of Ecological Importance. Project plans for turning this site into a Nature park and Sustainable Development centre are being developed. The purpose of this project is education, demonstration and research in sustainable environmental solutions including renewable energy, waste-water management and safe-guarding biodiversity. There has also been an initiative of planting indigenous trees and shrubs typical of the Mediterranean habitat.

In this area the remains of a destroyed megalithic site are also found. The Xrobb l-Ghagin site was built very close to a cliff edge which has been eroded in the last 5,000 years; therefore hardly any of the construction survives today. This site is very dangerous to access due to the undercut cliff that is still collapsing. The site is said to have been used from about 4,000BCE.

Recent pollution problems have arisen in the area of Xrobb l-Ghagin after the setting up of the Tuna Pens Fish farm just off Munxar Point at St. Thomas Bay. There have been plenty of undesirable changes in the area. The fish farms are considered to be an eyesore. Divers also complained the once clear sea water became permanently turbid. The sea water surface became covered in a mixture of engine oil from the boats and fish oil from the fish meal and fish remains. Offensive smells reach the coast and metal and plastic debris are often found in the Xrobb l-Ghagin and Munxar area.

This study is particularly focused on the Xrobb l-Ghagin area made up of Il-Hofra il-Kbira and il-Hofra iz-Zghira. Difficulty in accessing this area created some problems in conducting this study. The area is in fact not accessible by car and a walk of 45 minutes was

required everytime a field session was conducted. This means that the time of day had to be considered as if the field visit was done late in the afternoon, with the site being poorly lit, the return walk would be hazardous. Weather conditions also had to be considered everytime as the site is very risky during stormy weather and strong winds. This is also a reason why the site visits were never done alone but it was made sure that someone could accompany me for security purposes.



**Figure 1.1:** An aerial photograph of Malta



**Figure 1.2: An Orthophoto of the area of study**

Source: [www.mepa.org](http://www.mepa.org)

### 1.3 Contributions of Study

There have been few intensive studies on the coastal geomorphology of the Maltese Islands. Most studied on the Maltese coastal geomorphology have in fact been on a general scale whereas a few more detailed studies have been done of the Northern part of the islands by graduating university students. Regional detailed studies may therefore be considered as a contribution to the study of coastal geomorphology on the Maltese Islands. By focusing on a particular area, original features of a landscape may be found which would lead to more specific classification. This will hopefully also contribute to the eventual mapping of the geomorphology of the Maltese Islands. Such studies will aid future assessments of which our islands are most prone to in various regions and situations.

Research in coastal geomorphology will also raise awareness about a vital aspect of the natural heritage present on the Maltese Islands, this being coastal geomorphology. Since the study is a mostly qualitative piece of research it makes it easier to be understood by laymen. This might aid in the preservation of Malta's coastline, as it should play a role in socio-economic decision making. Models of landform evolution may help in preventing land degradation by showing how intervention would affect the system (Goudie, 1990). This is most efficient when carried out using a Geographic Information System (GIS) techniques.

My personal interest in geomorphology started while at the Università degli studi di Modena e Reggio Emilia in Italy while on *European Community Action Scheme for the Mobility of University Students* (ERASMUS) exchange program. Here particular attention was given to Earth Sciences and practical research on rocks and rock formations helping to provide knowledge on how to recognise particular formations from others, ways to make measurement accurately, mapping and other methods which help in conducting an effective

geomorphological study. While writing this dissertation, a visit was paid to the Biblioteca Universitaria Scientifico-Naturalistica, in Modena to obtain more professional information from books, reviews, maps and other resources which here were lacking. This visit proved to be very useful especially in the writing of the literature review.

### **1.3 The structure of the Dissertation**

This dissertation has the following structure.

**Chapter 1** has given a detailed description of the field site; describing its exact location, human influences that might have caused or will cause a change in the area and other important factors that are essential in order to familiarize one's self with the study. The aims of the study were also discussed so as to give a clear idea of what the study will be about and what mindsets and perspectives should be kept in mind.

**Chapter 2** is an introduction to coastal geomorphology as a study area and the geology of the Maltese Islands. Here these factors are illustrated clearly in order to provide a solid foundation for this study.

**Chapter 3** is a review of all the literature considered to be of vital importance to the significance of this study. A lot of research was done before the actual field study was carried out. The literature review mentions all the necessary sources where data for such a study was obtained.

**Chapter 4** discusses the methodology of observation, mapping, ground-based photography and data collection. The methods used in creating the geological map and the geomorphological map are described step by step in the way they were actually carried out.

**Chapter 5** provides the final results deriving from the methodology applied to carry out the dissertation on the studied field. This chapter deals with the analysis of these results, trying to comment them in a critical way.

**Chapter 6** presents the conclusion. This final chapter provides a synopsis of the main results, discussing and answering the hypothesis. Moreover, it offers some proposals for future studies. The thesis concludes providing a critical evaluation of whether the aims of the study have been reached or not.

## **Chapter 2**

# **INTRODUCTION TO GEOLOGY AND COASTAL GEOMORPHOLOGY OF THE MALTESE ISLANDS**

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## **2.1 Overview**

This chapter gives a brief description of coastal geomorphology. This is followed by a very detailed account of the geological aspect which is an important characteristic to be considered when studying geomorphology. The geological characteristics mentioned are the ones which helped shape the Maltese Islands and therefore also influenced the area of study.

## **2.2 The Coast and Coastal Geomorphology**

‘Coast’ is defined as the meeting and overlapping of land and sea. Many geographers, however, have difficulty in agreeing on the width to which the term coast can be applied. On one thing they do see eye to eye though, they all agree that the processes which affect the coast can be divided into terrestrial, marine and atmospheric. These three classes are responsible for the moulding of the coasts in various topographies.

The coast is a very important area for us humans. This zone provides us with a place for relaxation and recreation but it is also essential for our economy. In essence it is the main

location where importation and exportation of goods into a country takes place. It also provides a number of resources extracted from the sea. Consequently, one can say that the coastal area undergoes a great deal of pressure and therefore needs a lot of care.

Coastal geomorphology is the study of how the ocean tides, waves and currents shape the Earth's shorelines or in other words, it is the study of the development, configuration and distribution of the surface features of the coastal zone. This includes erosional features such as those experienced by sea cliffs and wave-cut platforms and also depositional or constructional features such as spits, bars and sand dune systems which are produced by the deposition of material by waves. The coastline is a very dynamic zone where erosion and deposition cause changes to occur both in short and long time spans.

## **2.3 Geology of the Maltese islands**

The geology of the Maltese Islands is relatively simple and young when considered within a geological time frame. The layered rocks found on the surface of the Maltese Islands are composed of tertiary limestone, marls and clays with subsidiary quaternary deposits. These were formerly all sheets of unconsolidated sediments deposited down on the sea bed during the Oligocene and Miocene periods and therefore dating back to 30 to 35 million years ago. The original marine sediments were later lifted up above sea level and hardened by many processes of induration but without destroying the features that evidence their origin beneath the sea (Pedley & Clarke, 2002b). In fact, according to Hyde (1995), the fossil remains and inorganic constituents which make up the Maltese rock show that these rocks were deposited along the

continental coastline at different distances and depths. The oldest rock, the Lower Coralline Limestone dates back to the Tertiary period while the youngest rock is said to be about 10 million years old.

These formed from deposits of remains of marine organisms, in fact, Calcium Carbonate ( $\text{CaCO}_3$ ) which makes up the Maltese Limestone was once a major component of marine shells, corals and algae. These rocks were uplifted by tectonic movement and started being eroded by rain, wind, changes in the climatic conditions and wave action forming the Maltese landscape as known today. The distinctive formations in the succession have contrasting lithologies, and this is reflected in the characteristic topography and vegetation which they produce.

## **2.4 Geological stratigraphic of the Maltese Islands**

The five types of rock that make up the Maltese Islands are:

- Upper Coralline Limestone;
- Green Sands;
- Blue Clay;
- Globigerina Limestone;
- Lower Coralline Limestone.

<i>Epoch</i>	<i>Stage Years BP</i>	<i>Formation</i>	<i>Maximum Thickness (m)</i>
U. Miocene	Tortonian (12-7.5 Ma)	Upper Coralline Limestone	104-175
		Greensands	0-16
M. Miocene	Serravallian (13-12 Ma)	Blue Clay	0-75
M. Miocene	Langhian (15-13 Ma)	Upper Globigerina Limestone	5-20
		Upper Main Conglomerate (C2)	
L. Miocene	Burdigalian (20-15 Ma)	Middle Globigerina Limestone	0-110
		Lower Main Conglomerate (C1)	
L. Miocene	Aquitanian	Lower Globigerina Limestone	5-110
U. Oligocene	Chattian	Lower Coralline Limestone	140 (visible) 236 (borehole)
Eocene to Lower Cretaceous		Clays and dolomitized limestone	+3000 (borehole)

**Table 2.1: Name, age and thickness of the rocks forming the Maltese Islands after Spratt (1843), Felix (1973)**

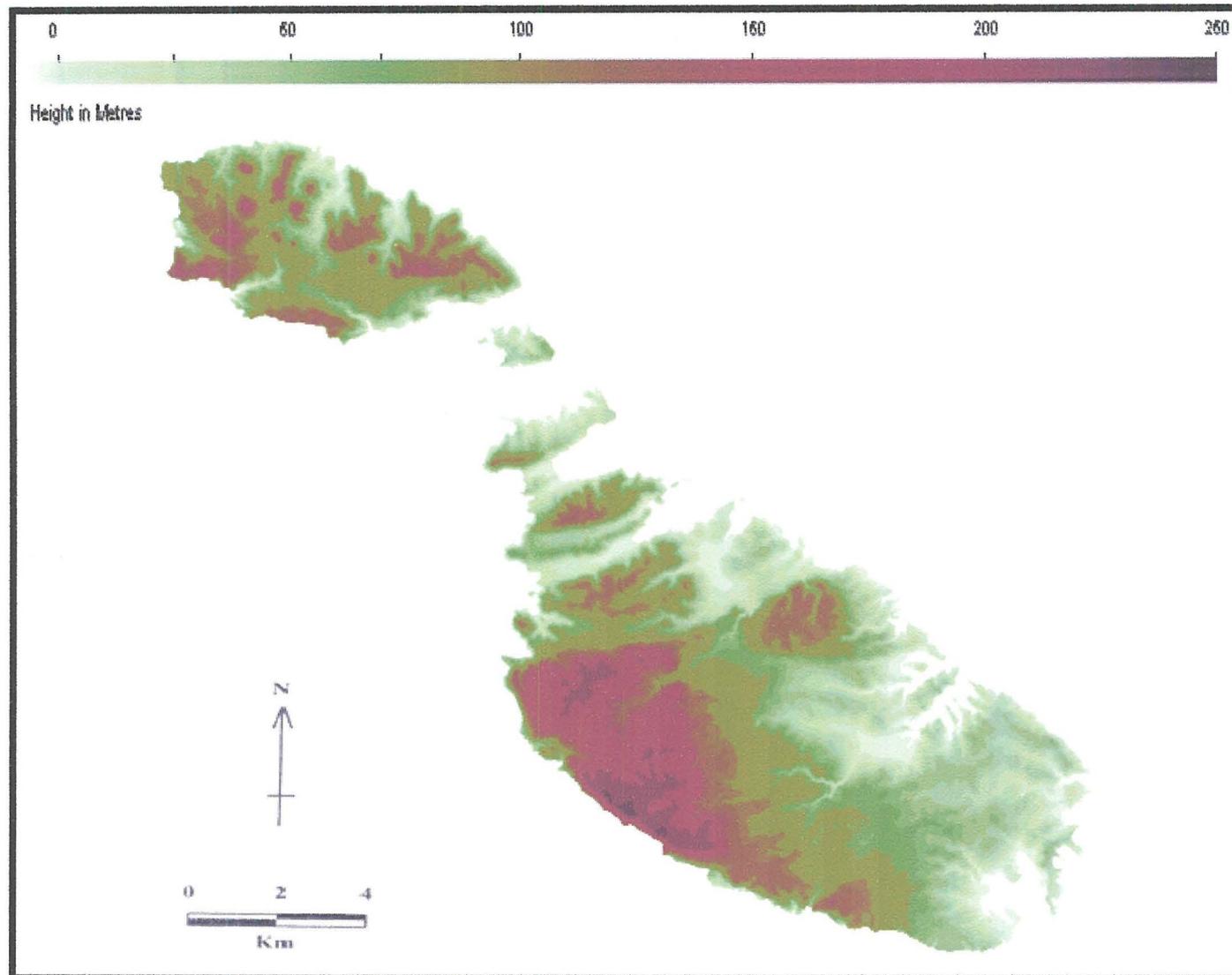
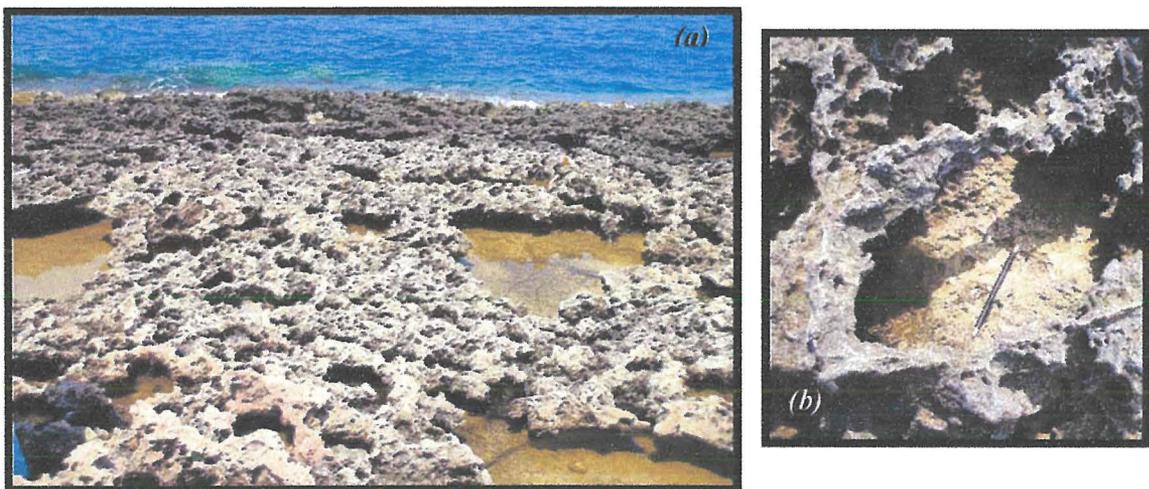


Figure 2.1: 3D Elevation Map of the Maltese Islands. Contours are shown at a 10m Interval.



### 2.4.1 Lower Coralline Limestone

Lower Coralline Limestone is a very hard, pale grey rock. The coralline algae which compose it indicate the deposition in a shallow gulf environment. It forms sheer, vertical coastal cliffs located mostly on the West and South-West of Malta. In the vertical cliffs near Xlendi, Lower Coralline Limestone in Gozo actually reaches the height of 140m. When found inland, this rock forms barren grey limestone pavement plateaux.



**Plate 2.1: Karst Landscape in the North Eastern Coast of Malta**

Lower Coralline Limestone is very prone to the formation of karstic landscape. This occurs when rain passes through the atmosphere picking up carbon dioxide ( $\text{CO}_2$ ), which dissolves in the water. Once the rain charged with the dissolved  $\text{CO}_2$  reaches limestone terrains and infiltrates the rock, it forms a weak solution of carbonic acid ( $\text{H}_2\text{CO}_3$ ), dissolving the surface especially along fractures and joints in the limestone bedrock. An underground drainage system develops over time, allowing karst features to form. The dissolution of limestone formations

depends on the calcium carbonate ( $\text{CaCO}_3$ ) present in limestone, the carbon dioxide ( $\text{CO}_2$ ) present in the atmosphere and on water ( $\text{H}_2\text{O}$ ) resulting from precipitation.

Small particles of rocks which are not dissolved by water, collect in the holes and form Terra Rossa soil. Small plants typical of karst areas grow in these tiny shallow patches of soil such as the Mediterranean Thyme, the Mediterranean Heath, the Maltese Spurge and other Geophytes and Xerophytes.

## **2.4.2 Globigerina Limestone**

Globigerina Limestone is the most widespread rock on the surface of the Maltese Islands as it covers over approximately 70% of the area of the Islands most of which is now built-up whilst the remaining area is cultivated or quarried. It forms a broad, gently rolling (smooth) landscape which as topography is most characteristic of the South and South-East of the Islands. Variations in the thickness of this formation are considerable as it ranges from 23m near Fort Chambray in Gozo to 207m in the Marsaxlokk area. A thick succession is also developed in the Valletta Basin.

John Murray in 1888 applied the microscope to the study of thin sections of the rocks. He realised that their composition was identical to that of the globigerina ooze which is accumulated on vast areas of the present day ocean floors. Accordingly, he remarks in his 1890 account of the Maltese rocks:

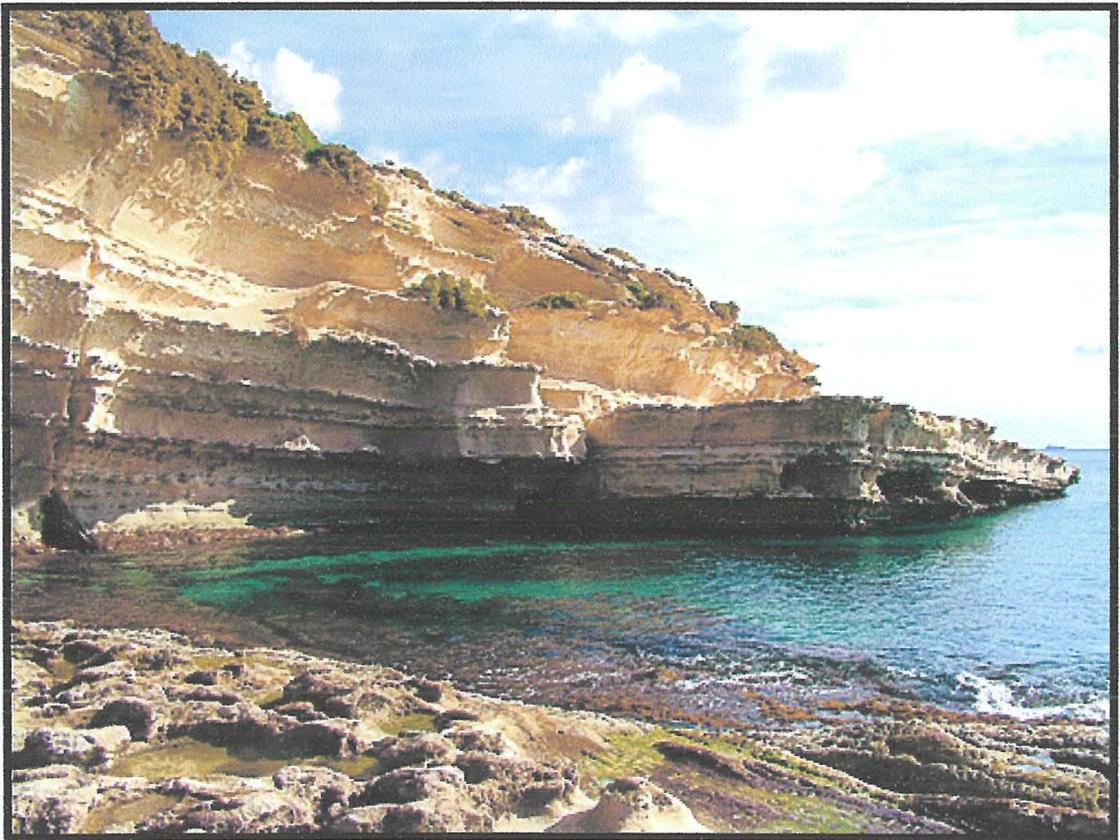


**Plate 2.2: Globigerina Limestone shore Platform at Sliema**

*“The great series of rocks known under the name Calcareous Sandstones are much better designated by the term Globigerina Limestone, for they are chiefly composed of these minute shells and their broken-down remains, and none of the beds are largely made up of quartz sand, though that idea is conveyed by the word sandstone.”*

This rock formation consists of very soft, yellow to pale-grey limestone mainly composed of *planktonic globigerinid foraminifera*. When found near the coast, it is very susceptible to erosional processes present there. Lithologically and palaeontologically Globigerina Limestone formation is divided into lower, middle and upper subdivision, with conspicuous phosphatic conglomerates which are also known as nodule beds, nodule layers or nodule seams (Spratt, 1842; Adams, 1870; Murray, 1890) marking an important unconformity at the base of each subdivision. The Phosphorite horizons are said to have resulted from a sudden elevation or subsidence of the sea-bed which brought about a change in the conditions under which the sea-organisms lives causing their death and eventually fossilisation.

Rizzo (1932) was the first who suggested that Globigerina Limestone should be subdivided into three layers. Upper Globigerina Limestone is a fine-grained planktonic foraminiferal limestone which is made up of an upper and lower layer consisting of brown-weathering freestone, similar in appearance but much inferior in working qualities to that of the lower Globigerina. These two layers are separated by an intermediate layer of blue-grey marls. Certain flaggy beds are resistant to heat and were formerly used extensively for tiling ovens and for building small cooking stoves.



**Plate 2.3: Globigerina Limestone formation at St. Peter's Pool, Delimara**

Middle Globigerina Limestone is a planktonic foraminifera-rich structure consisting of white, soft carbonate mudstones locally passing into pale-grey marly mudstone. The succession is thickest in the Delimara area. Numerous nodules and impersistent layers of chert have formed locally in the lower portion by replacement of the limestone with cryptocrystalline quartz. These middle globigerina charts are the only conspicuous development of hard silicon rock known in Malta. They were used for the manufacture of stone implements by the prehistoric inhabitants of the Islands.

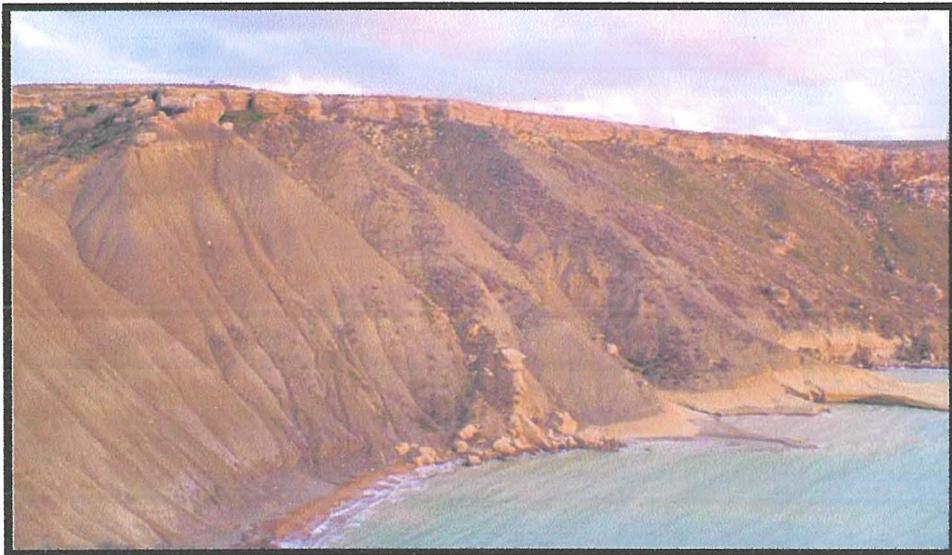
Lower Globigerina Limestone, also known as *Franka* in local terms, is a pale cream to yellow planktonic foraminiferal packstones which rapidly becomes wackestone above the base. The top of the member is marked by an omnipresent hardground. Lower Globigerina Limestone provides most of the building stone in Malta. This, in fact, is quarried from one specific area of the Island, namely the eastern district including Mqabba, Luqa, Safi, Gudja, Qrendi and Siggiewi.

### **2.4.3 Blue Clay**

Blue Clay is a very soft rock overlying Globigerina Limestone. It is a bluish grey clay or marl. It is very easily eroded especially when wet. When it is exposed, it slumps out of the slopes and covers the underlying rocks, forming taluses of about 45°. As a result it gives the impression that hills are made up of Blue Clay. Good examples of talus slopes are found at Għajn Tuffieħa, Gnejna Bay, Selmun and Nadur in Gozo.

Thickness varies from 75m at Xaghra, Gozo to nil in Eastern Malta, where Upper Coralline Limestone rests directly on Globigerina Limestone. Deposition of the Blue Clay is said to have occurred in an open muddy water environment where water depths reached 150m for the lower part of the formation.

In the Maltese Islands, Blue Clay plays a very crucial role owing to its one property that is unique amongst all the rocks of the Maltese Islands. Blue Clay is an impermeable rock, making the overlying land very fertile. Such surfaces produce more run-off and therefore also a greater number of streams. In the case of Malta, Blue Clay gives rise to the perched aquifer which in Malta, where water is lacking, is vital to provide water to agricultural areas especially in the northern parts of Malta.

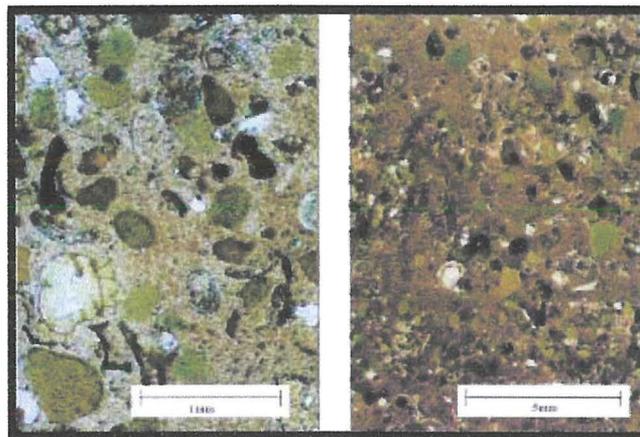


**Plate 2.4: Blue Clay slope, Gnejna Bay**

#### 2.4.4 Green Sands

Greensands consist of bioclastic limestone which is rich in glauconite deposited in a warm sea. When unexposed the rock has a green colour but when exposed it is oxidised to an orange colour. The maximum thickness is found at Il-Gelmus in Gozo.

This type of rock is easily eroded and forms sand which covers beaches such as Ramla l-Hamra in Gozo and Ghajn Tuffieħa. It forms no particular landform mostly due to its thinness and absence in most areas of the Islands.

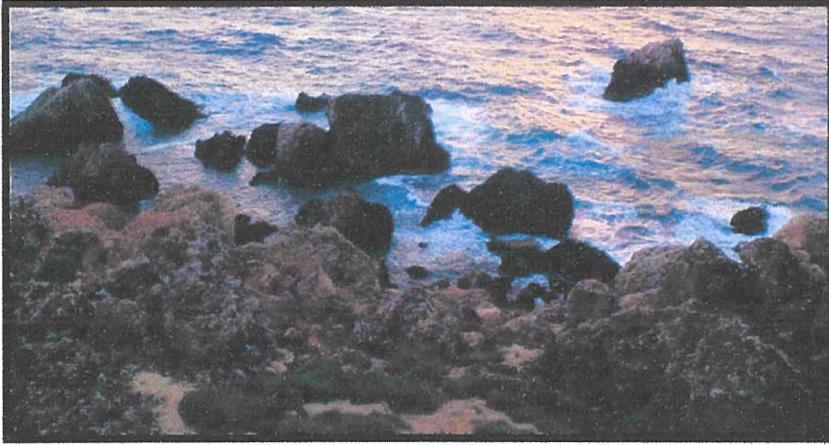


**Plate 2.5: Greensands under the microscope**

#### 2.4.5 Upper Coralline Limestone

Upper Coralline limestone is the uppermost and youngest Tertiary formation in the Maltese Islands which reaches a thickness of 160m in the Bingemma area. This particular stratum is very similar to Lower Coralline Limestone both in its chemical composition and

palaeontological grounds, implying its deposition in shallow waters just like Lower Coralline Limestone.



**Plate 2.6: Upper Coralline Limestone boulders at Qarraba**

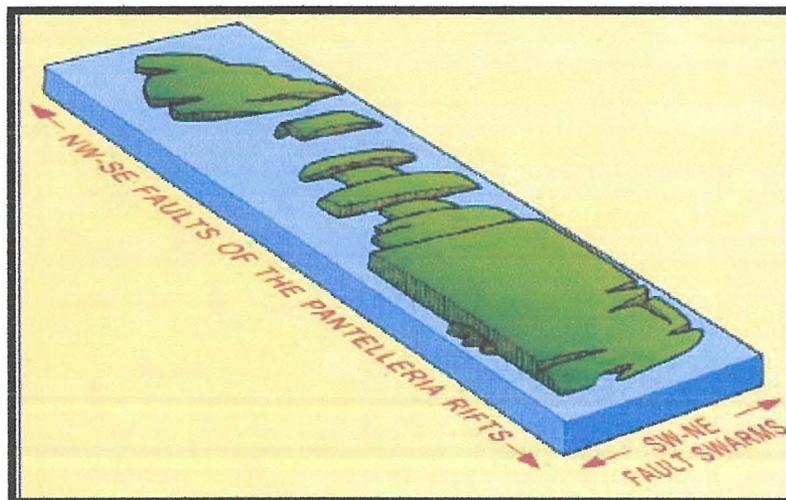
However, Upper Coralline Limestone forms cliffs which are different from the Lower Coralline Limestone cliffs. Upper Coralline Limestone lies on the softer rocks of Blue Clay and Greensands. These two rocks erode more quickly than Upper Coralline Limestone and move downhill. Upper Coralline Limestone remains unsupported and collapses because of its own weight. Large Upper Coralline Limestone boulders fall on hillsides covered with Blue Clay surfaces or near the coast in the sea. Most coastal areas of Upper Coralline Limestone are characterized by a series of partly submerged boulders along the shoreline which are called scree slopes. Most Upper Coralline Limestone and Lower Coralline Limestone cliffs are inaccessible, therefore, some flora and fauna which have been destroyed in the rest of the Maltese Islands can still be found in these areas. When found inland, Upper Coralline Limestone forms a typical karst pavement.

## 2.5 Structural geology

In the Maltese Islands there are numerous other topographical features mostly caused by tectonic movement. Amongst these features, one can find several faults. These faults were caused by fissures and upward and downward movement of the land.

There are two major faults, these being:

- The Great Fault running from Madliena to Fomm ir-Rih.
- Maghlaq fault running from Benghisa Point to Is-Sikka



**Figure 2.3: The Maltese Fault Systems**

Source: Pedley, 2002b

The Maghlaq Fault caused the island of Malta to tilt towards the east. As a result, the North-West coast of the island consists of cliffs while the South-East coast is made up of low lying coasts or shore platform. This tilting also led to the drowning of river valleys in the Valletta harbour area forming rias which were ideal as a site for a harbour. These faults also caused the formation of Filfla. Filfla was once a part of Malta but the land in between fissured and drowned into the water causing the small island.

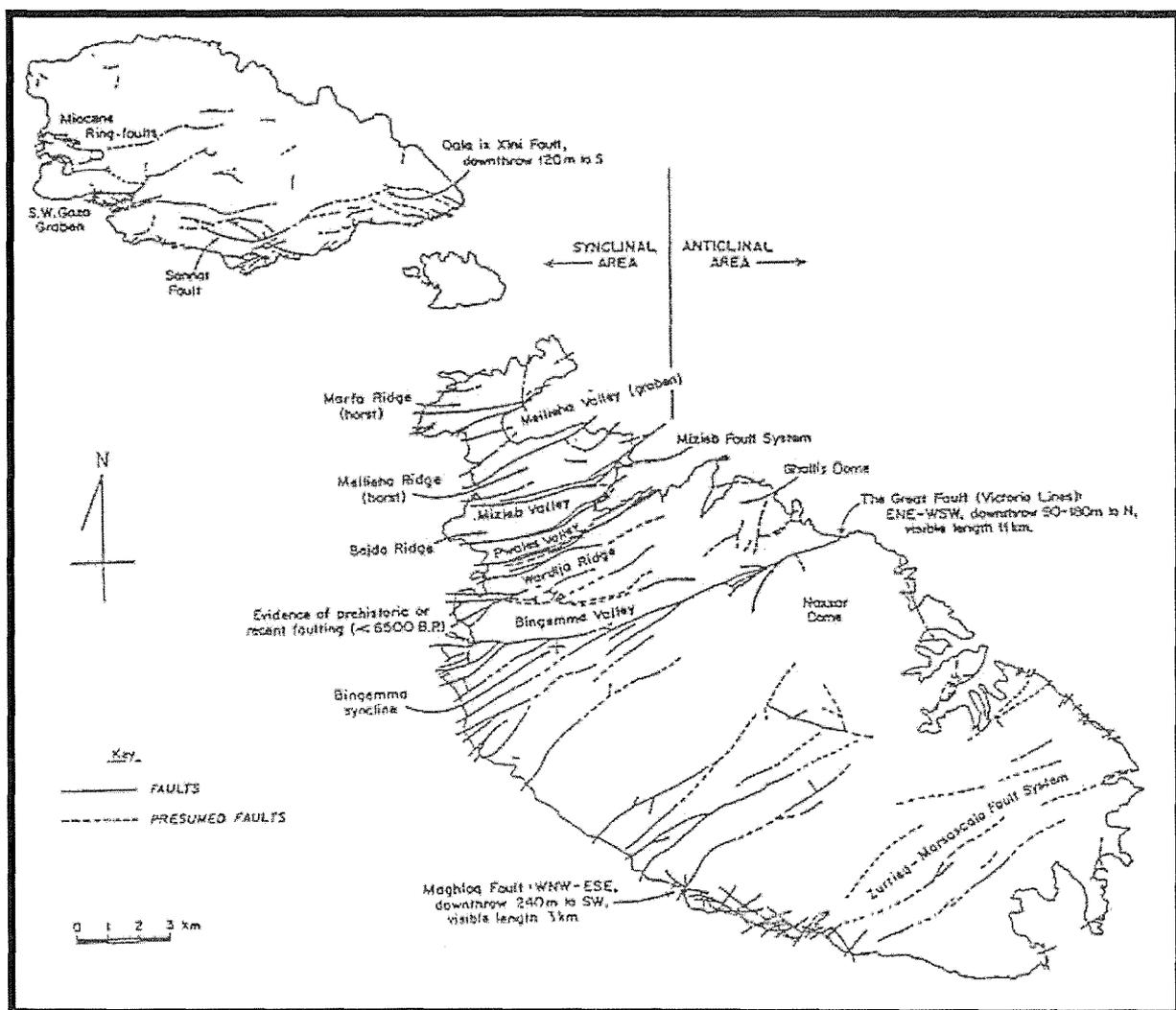


Figure 2.4: Tectonic Structure of the Maltese Islands

Source: Alexander 1988

There are also a series of parallel faults north of the Great Fault. The parallel faults in the Northern area of Malta created a series of ridges and valleys these being: Marfa Ridge, Għadira Valley, Mellieħa Ridge, Mizieb Valley, Bajda Ridge, Pwales Valley, Wardija Ridge, Bingemma Valley and Victoria lines/Great Fault. Gozo and Comino are both ridges while the channels in between are valleys that have been drowned by the sea.

The Maltese archipelago is linked to the Ragusa peninsula of Southern Sicily by a submarine ridge which is nowhere deeper than 200m and is mostly less than 90m. This ridge continues southwards towards North Africa and Lampedusa.

# **Chapter 3**

## **LITERATURE REVIEW**

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## 3.1 Overview

Four main venues constitute the information found in this chapter. The main venue was the University of Malta Library given that it was the easiest to get to and where a significant amount of information could be obtained especially from the many books regarding the themes discussed in this dissertation.

Secondly, more recent and updated information was obtained from the internet. Several websites which provided the download of abstracts and articles of recent research were accessed during the period of the dissertation to enhance what was found out from books.

To develop the research and find out some more information related to the subject I made use of a foreign library; in this way the study was conducted utilizing data coming from other sources and not only taking into consideration the only information given at disposal by the university or online. Namely, I made use of the “Biblioteca Universitaria Arca Scientifico-Naturalistica”, at the Università degli studi di Modena e Reggio Emilia in Italy. Moreover, I had the opportunity to get plenty more information staying in contact and keeping a direct correspondence with experts of the fields studied.

The understanding of the formation of landforms expected to be found on the examined site as well as basic literature about geomorphology, geology, coastal geomorphological processes, erosional and depositional processes and sea-level rise was found in the University of Malta library mainly in text books. Even though many of these books were dated (c.f. Reference List), they offered excellent information to base my knowledge on before conducting the actual field investigation.

The visit to the University of Modena Library was very profitable because I had the opportunity to deal directly with gaining information from unique sources which are not available in Malta. This mainly included a number of journals containing scientific papers regarding studies and aspects in geomorphology and earth science.

Access to online journals such as the *Quaternary Science Reviews Journal*, *Marine Geology Journal*, *Tectonophysics Journal* and *Earth Science Reviews Journal* gave me the possibility to download papers where very recent and updated information could be found concerning the Mediterranean region and even regarding Malta in particular.

## **3.2 Geomorphology**

Geomorphology, as translated from Greek, is the science that aims to study and interpret landforms on the earth's surface and the elements that generate them and change them. In essence, it involves the study and the interpretation of the evolution of landforms, mainly those

produced by the processes of erosion. It may also be described in its simplest form as the correlation between landforms and the underlying rocks as affected by atmospheric, oceanic and terrestrial processes.

The forces that determine the evolution of the relief can be either endogenous, which are created by tectonic, seismic and volcanic processes, or exogenous processes related to the atmosphere, hydrosphere and biosphere.

*“Geomorphology is the science concerned with understanding the form of the Earth's land surface and the processes by which it is shaped, both at the present day as well as in the past. British geomorphologists are involved in research into the processes of weathering and erosion, sediment transport and deposition, the characterization of landforms and the materials of which they are composed” (British Society for Geomorphology).*

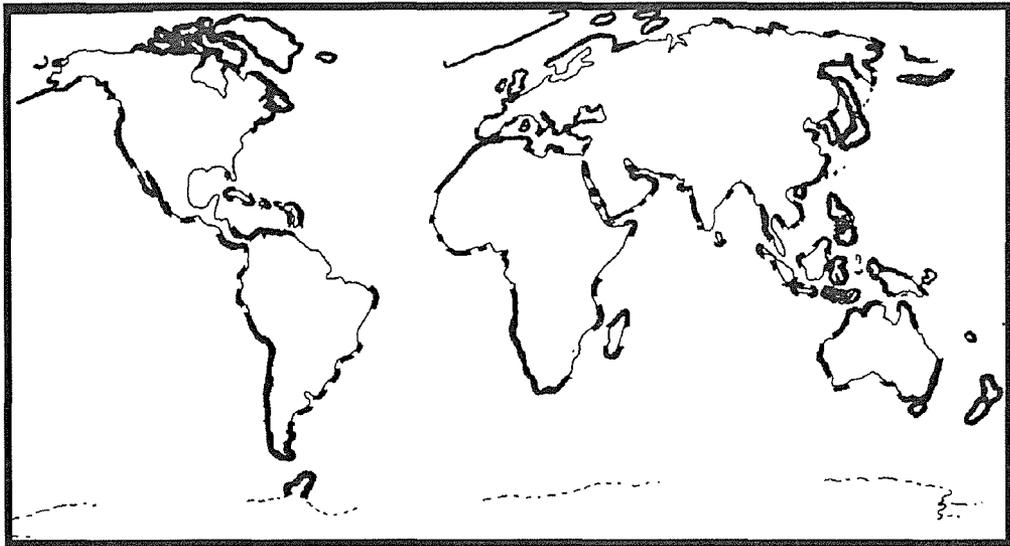
According to Ritter, (1986:2) geomorphology, which is generally simply defined as the study of landforms, should be divided into a four-dimensional science. Firstly explaining the origin and development of landforms on a physical and/or chemical basis and secondly, predicting future landform changes on a quantitative basis.

### **3.3 Geomorphology of Rocky Coasts**

Webster's *Third New International Dictionary* gives a clear and exhaustive definition of 'rocky coast' as 'a coast that is cliffed and yet composed of consolidated material irrespective of its hardness.' It has been estimated that sea cliffs make up around about 80 per cent of the world's oceanic coasts (Isakov, 1953; Emery and Kuhn, 1982).

The study of rocky coasts, in general, is very often neglected. Perhaps, this is because cliffs and shore platforms are thought to be relatively simple landforms and therefore they are often ignored. American geomorphologists have done a substantial amount of work and studies on beaches, barriers, marshes, deltas and coastal plains and gave little attention to rocky coasts. According to Bird (in Sunamura, 1992), this is because of the scarcity of coastal cliffs and shore platforms along the coastline of the United States. On the other hand in countries like Japan, Great Britain, France and New Zealand, rocky coasts are very abundant. Sunamura himself suggests that only recently, rocky coast geomorphology has been described in parts of coastal geomorphology textbooks. Several geomorphologists (Steers, 1971; Davies, 1972; King, 1961, 1984; Bird, 1976, 1984, 1985, 2005; Pethick, 1984; Hughes & Masselink, 2003) have mentioned rocky and cliffed coasts in their coastal geomorphology textbooks. However, few books amongst which: *The geomorphology of rock coasts* (Trenhaile, 1987) and *Geomorphology of rocky Coasts* (Sunamura, 1992) have actually been written with rocky coasts as their main focus.

The authors referred to above have all illustrated the main elements which influence coastal processes, these being: the trend of the coastline, sea level change, aspect, climatic conditions, geology and structural factors, wind and waves as well as humans. All these authors give thorough explanations of wave processes and the resultant outcome on the coast to eventually form cliffs and shore platform and to generate landslides, falls and topples. Chemical, physical and biological weathering processes are described with reference to erosional features such as arches and stacks which are found along the coastal region. Some texts have even considered coastal management techniques.



**Figure 3.1: Generalized distribution of sea coasts backed by cliffs (black bold)**  
 (after Isakov 1953, and Emery and Kuhn 1982)

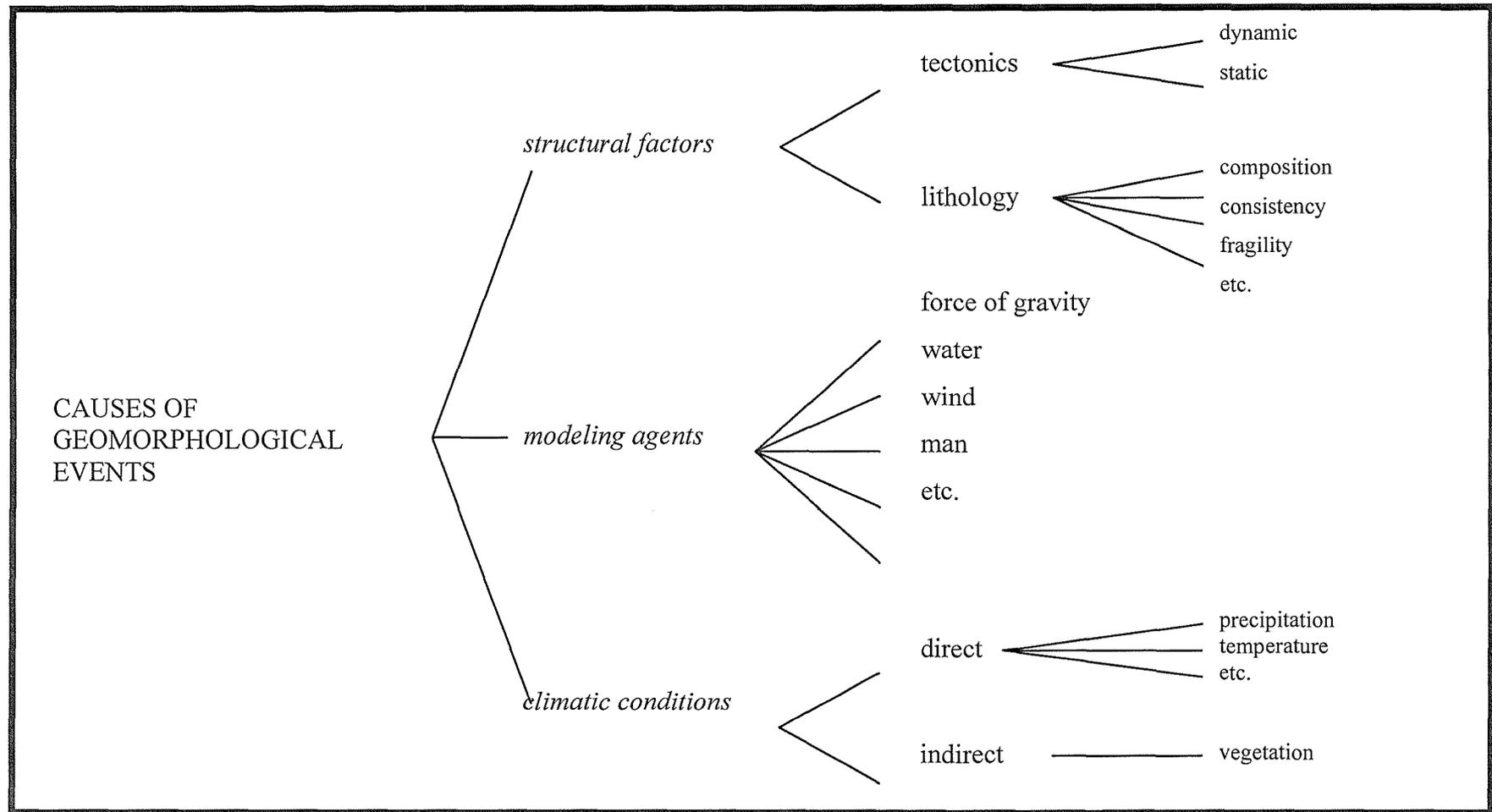
It has been estimated that sea cliffs make up around about 80 per cent of the world's oceanic coasts (Isakov 1953, Emery and Kuhn 1982). The shape of the cliff profile is generally modelled by factors such as geology, climate, wave and tides, vegetation, water depth, the type and amount of beach material at the cliff base, the topography of the cliff-top area and changes in the sea level. Sub-aerial processes, such as water run-off after heavy rain, have contributed to the dissection and cutting back of many marine cliff faces in varying degrees but cliff recession is maintained by basal marine erosion (Bird, 1985).

The measurement of the rates of erosion and retreat of unconsolidated cliffs typically depends on comparison of maps and aerial photographs. Goudie (1981) gives examples of this method in use, mentioning Steers (1951) on the Suffolk coast, Agar (1960) on the Yorkshire coast and Valentin (1954) on the coast of Holderness, who estimates accuracy of map comparison to be  $\pm 5\%$ .

The Maltese coastline is mainly made up of slowly retreating limestone cliffs. In some areas, it is generally possible to find collapsed boulders where underlying blue marls have been washed out. Sandy beaches are very limited and are generally located in the Northern part of Malta. Some examples are Golden Bay, Mellieha Bay and ir-Ramla in Gozo (Paskoff and Sanlaville, 1978).

Figure 3.2 shows the how geomorphological events can be caused by structural factors, modelling agents and climatic condition. The structural factors can occur in a tectonically or lithological manner. Tectonics can only be either dynamic or static while lithology includes the phenomenon of composition, consistency and fragility. The force of gravity, water, wind and man make up what are considered as modelling agents. Climatic conditions can be subdivided into two. These are direct and indirect climatic conditions. Direct climatic condition consists mainly of precipitation and temperature. Vegetation is also considered as a climatic condition even if it is an indirect factor.

Figure 3.2: Causes of Geomorphological Events



Source: Panizza, M., 2005

### **3.4 Erosion of Solid Rocks – Shore platforms and cliffs**

Trenhaile (1987) provides a thorough evaluation of the geomorphology of rock coasts. He suggests that there are four main processes by which the sea achieves erosion of consolidated rock. These are: chemical weathering, corrosion, attrition and hydraulic action. Generally, erosion takes place during high-energy conditions such as storms therefore, observation of these processes is exceedingly difficult. In fact, there are very few techniques by which these processes can be measured. One example of these methods was given by Mitsuyasu (1967 in Sunamura 1992). He suggested using a dynamometer to measure shock pressures of breaking waves.

In keeping with the explained affirmation given by Davies (1980) and Clark (1979) six processes which control cliff erosion may be listed. These are:

1. Quarrying: quarrying also known as attrition is the process of fragmentation of rocks and boulders which have already been eroded from the cliff face. During this process of attrition, rocks and boulders are broken down into smaller and more rounded particles.
2. Abrasion: the wearing down of rocks through the friction caused during the contact of the cliff with rock fragments. Abrasion takes place when waves hurl pebbles and sand grains at a cliff face. This causes gradual rounding in rocks and its gradual reduction in size. The rate at which abrasion takes place depends on the amount of material which is being carried and also on the resistance of the cliff itself.
3. Water-layer weathering: the alternate wetting and drying of the shore platform caused by tidal movements and wave variation. This allows a range of complex weathering processes, such as hydration, oxidation, salt crystallization and swelling of rock grains to

take place. These processes usually require high temperatures and permeable rocks to occur.

4. Solution of calcareous rock: occurs when carbonic acid in sea and rain water dissolves limestone rock.
5. Subaerial weathering: when erosion is caused by factors which are non-marine but rather processes like rain falling directly onto the cliff face, surface runoff of water from the land, winds and frost.
6. Bio-erosion: the process that includes the smoothing of rock by browsing invertebrates and fish. Also by chemical action due to exudates from organisms.

Other two main factors of erosional processes that can be mentioned are:

- Wave pounding – the process of the energy generation that occurs with the collision and crash of waves against the base of the cliff;
- Hydraulic pressure – the process of compression of air parcels which get trapped in the joints of the cliff or between a breaking wave and a cliff. This leads to the weakening of the cliff given that this collision causes an increase in pressure.

Table 3.1 give a classification of the main erosional processes occurring on rocky coasts with their respective description and the resultant conditions.

**Table 3.1: Summary of the main erosional processes on rocky coasts**

<u>PROCESS</u>	<u>DESCRIPTION</u>	<u>CONDITIONS CONDUCTIVE TO THE PROCESS</u>
<b><i>Mechanical Wave Erosion</i></b>		
Erosion	Removal of loose material by waves	Energetic wave conditions and microtidal tide range
Abrasion	Scouring of rock surfaces by wave-induced flow with mixture of water and sediment	'Soft' rocks, energetic wave conditions, a thin layer of sediment and microtidal tide range
Hydraulic Action	Wave-induced pressure variations within the rock causes and widens rock capillaries and cracks	'Weak' rocks, energetic wave conditions and microtidal tide range
<b><i>Weathering</i></b>		
Physical weathering	Frost action and cycles of wetting-drying causes and widens rock capillaries and cracks	Sedimentary rocks in cool regions
Salt Weathering	Volumetric growth of salt crystals in rock capillaries and cracks widens these capillaries and cracks	Sedimentary rocks in hot and dry regions
Chemical weathering	A number of chemical processes remove rock material. These processes include hydrolysis, oxidation, hydration and solution	Sedimentary rocks in hot and dry regions
Water-layer levelling	Physical, salt and chemical weathering working together along the edges of rock pools	Sedimentary rocks in areas with high evaporation
<b><i>Bio-erosion</i></b>		
Biochemical	Chemical weathering by products of metabolism	Limestone in tropical regions
Biophysical	Physical removal of rock by grazing and boring organisms	Limestone in tropical regions
<b><i>Mass movements</i></b>		
Rock falls and toppling	Rocks falling straight down the face of the cliff	Well joined rocks, undercutting of cliff by waves
Slides	Deep-seated failures	Deeply weathered rock, undercutting of cliff by waves
Flows	Flowing of loose material down a slope	Unconsolidated material, undercutting of cliff by waves

Source: Hughes, M. & Masselink, G. (2003)

## **3.5 Influences on coastal processes**

Changes in the coastline may be caused by various factors. On a rocky coastline these may include:

- The trend of the coastline;
- Variations in sea level;
- Aspect;
- Wind and Waves;
- Inland morphology;
- Climatic Conditions;
- Geology and Structural Factors.

Further details are given below.

### ***3.5.1 The Trend of the coastline***

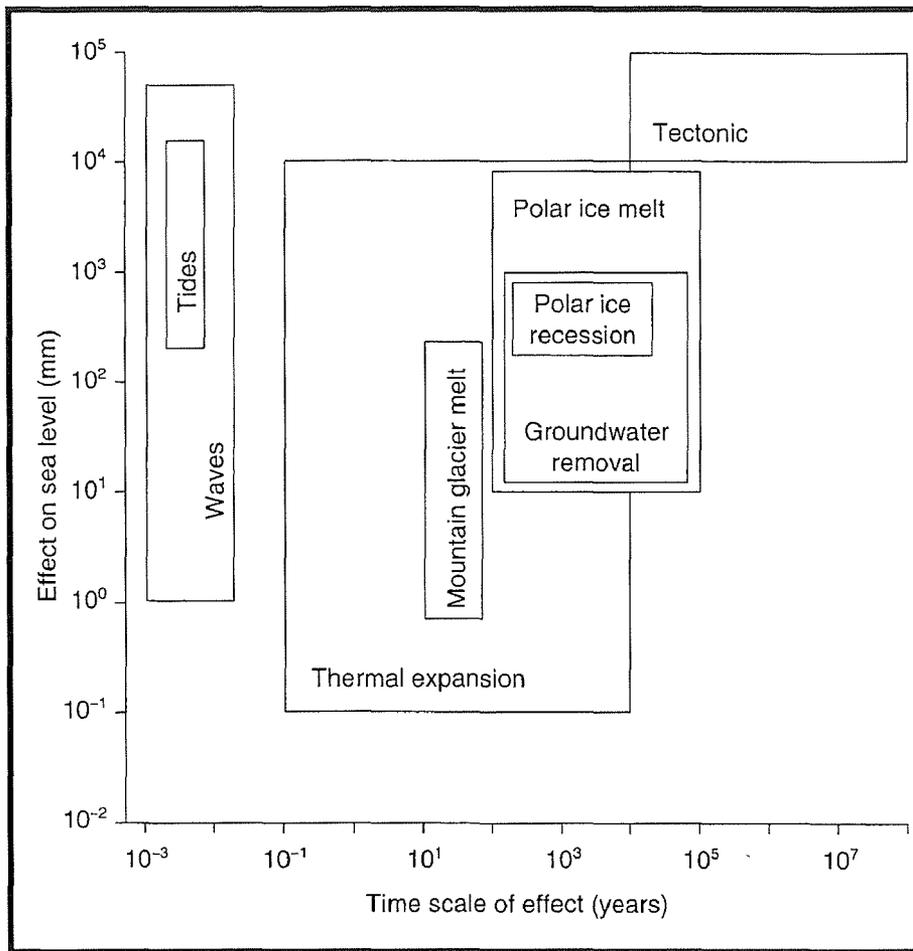
The trend of a coast is an important factor which may influence the rate and position of where erosion occurs, the direction of longshore drifting, the formation of beaches, spits and bars and the situation of large dune areas. Here the fundamental correlation is that between direction which the coastline faces, the direction of the maximum fetch, and that of the prevalent winds (Small, 1978:418).

### **3.5.2 Variations in sea level**

The rise in sea level has been a public concern since the late 1960's, mainly owing to the floods in Venice. It is now known that with the melting of the glacial ice, a large amount of water will enter the ocean basins and result in a sea level rise. In fact, in the early 1980s, a prediction of a rise of 56-345cm by 2100 was proposed and it further raised the alarm amongst the people. The rise due to Global Warming is estimated at 9-88cm between now and 2100 according to the IPCC report of 2001. It has been estimated that if all the polar ice present today was to melt it would raise sea level by about 78m (Inman, 1983:6).

*“The large-scale processes most responsible for changing the elevation relationships between land and water, and thus initiating erosion and landform evolution, are tectonics and climate change.” (Dincauze 2000:227-8)*

The rise in sea level is essentially due to a number of factors, the main ones being thermal expansion of the upper layer of the ocean, the melting of glaciers and snow packs as air temperature rises. This will cause displacement of estuaries, enhance coastal erosion and the submergence of some low-lying islands.



**Figure 3.3: Sketch of the approximate range of magnitude of effects from several processes on sea level rise, and the time scale of these effects**

**Source: Bird, 1993**

As far as the Maltese Islands are concerned, it is presumed that major sea level rise is not occurring at the moment and it is considered insignificant as regards to coastal erosion (Caruana, 2006). While the effect of tides in Malta is considered to be irrelevant, rise in sea level may be set off by storm surges and tsunamis. The only tsunami recorded in Malta is that associated with the Messina Straits earthquake on 28<sup>th</sup> December 1908 where the sea level gauge recorded sea level fluctuations with a maximum crest-to-trough excursion of 2 feet 11.8 inches (= 0.91m).

<http://www.capemalta.net/news/Feature%201%20-%20Tsunami%20in%20Stromboli.html>

### **3.5.3 Aspect**

Aspect is simply the orientation of each cliff-face. It has a great influence on geomorphology through the contrasts in radiation, this effect is most evident between North and South-facing slopes, which eventually leads to differences in elements such as the hydrology and sediment transport rates of the cliff.

The difference in the intensity of geomorphological processes between the two opposing cliff face is a clear evidence of their different aspect. The greater radiation on south-facing and semi-arid slopes increases evapotranspiration rates such that water stress occurs in vegetation more quickly after rain. As a result, the vegetation cover is sparser and the species in these areas are more adapted to drought. Sparse vegetation encourages greater crusting of the soil surface and consequently, more surface run-off and more erosion by wash erosion. On North-facing slopes, on the other hand, soil moisture following rain, is maintained for a longer period of time, such that humid vegetation can grow, typically providing greater ground cover and superior conditions for soil to accumulate. Although these conditions improve infiltration rates and reduce surface run-off, they can also provide better conditions for mass movement due to the greater depth of soil and higher moisture content.

Kirkby, M. (in Goudie, 2001a) suggests that observations of semi-arid slopes generally imply that the difference in the aspect tends to maintain steep bedrock slopes on South-facing cliffs and gentler slopes mantled with soil and vegetation on North-facing cliffs.

### **3.5.4 Wind and Waves**

Wind in itself is a very important aspect to consider when studying coastal erosion. It generates waves and currents which eventually shape the coast. The differences in the strength and frequency of the winds is what determines the evolution of the coastline.

According to Pethick, the driving force behind almost every coastal process are waves. Wave action plays both a primary and a secondary role in the development of cliffs. Waves are generated by the friction between wind and sea. When waves break they may cause a lot of movement in the water for a brief time as they collapse. In the case of a wave breaking at the foot of a sea cliff, it causes a great deal of energy leading to maximum erosion. Wave erosion depends on the strength of the wave, the morphology of the coastline for example whether there are headlands or bays and also on the geology of the coastline which depends on the lithology and the geological structure for instances the faults, joints and bedding plains present in the rock.

*The point at which a wave breaks is determined by its deep water wave characteristics, the submarine topography, and the water depth which varies according to tidal and weather conditions. When a structure such as a sea cliff stands in water which is at the breaking depth of the incident waves. In these cases, waves break directly onto the structure. (Trenhaile, 1987: 11)*

### **3.4.5 Climatic Conditions**

Solar radiations, humidity in the air, atmospheric pressure, the type and quantity of precipitation and the temperature may all have an effect on the shaping of the coastline. The Mediterranean Region is characterised by mild wet winters and hot dry summers often experiencing drought. Rainfall is generally very punctuated this means that rain falls in a short period of time but with a high intensity. Annual rainfall is highly-variable and not evenly spread between the seasons. This causes a lot of erosion as water is not given time to seep through the rocks whilst run-off is more probable. Especially during the summer period, onion-skin weathering may occur due to the extreme high temperatures the rocks are exposed to during the day, and the fall in temperature during the night causing the rocks to expand and contract accordingly creating the peeling of the outer crustal layer (Caruana, 2006).

### **3.5.6 Geology and Structural Factors**

Geology is the science and study of the Earth, the materials composing it and their structure and the processes which evolve them. This comprises the study of rocks, soil and stones. Geology also studies the composition, structure, physical properties, history, and the processes that shape Earth's components. (<http://en.wikipedia.org/wiki/Geology>)

The structure of the coastal zone may be a key factor in understanding the causes of erosion. Apart from the above mentioned aspects that might cause coastal erosion, the structure of the rock itself is very important. These may be divided into three categories: lithology which is

essential when discussing erosion caused by water as it includes the permeability of the rock which make it more susceptible to erosion, the aspect of the rock's condition, the coastal stability and finally tectonics may also weaken the coastal zone making it more easily erodable as this may condition the coastal morphology in itself.

### **3.6 Geomorphology of the Maltese Islands**

The geomorphology of the Maltese Islands has been portrayed by House *et al.* (1961) and by Vossmerbäumer (1972) and Alexander (1988) while the theme of coastal geomorphology in the islands is described in the scientific papers by Guilcher and Paskoff (1975), Paskoff and Sanlaville (1978) and Ellenberg (1983) and Paskoff (1985).

More recent and updated information is lacking. However, during the process of research while conducting this dissertation, a number of undergraduate and Masters dissertations were found related to this subject. These had more recent geomorphological information found on the actual field where the students studied. Such dissertations include: Magri (1995), Buttigieg (1996), Said (2001), Marmara (2004) and Caruana 2006.

### 3.7 Tectonics

Tectonic features in the Maltese Islands were explained by Trechmann (1938), Pedley (1979), Illies (1980) Reuther (1984), Alexander (1988). Trechmann (1938) was the first to give a detailed explanation of the fault movement throughout the Miocene and Quaternary period with reference to the major faulting systems in the islands, namely: Qala fault, Victoria Lines fault and the Maghlaq fault. Pedley (1976) continued on this research to further analyse the faulting systems to ultimately produce a structure contour map along with a profile sections of the selected areas in the Maltese islands. This was an excellent aid to visualize the faulting on the islands.

Reuther (1984), in an article called *Tectonics of the Maltese Islands*, after careful study of the conditions, discusses the actual tectonics that have influenced the shape of the Maltese Islands. He assumed that “*the fracture pattern of the Maltese Islands is governed by two intersecting fault systems which alternate in tectonic activity*”. A NE-SW to ENE-WSW trending fault system crosses the islands and is intersected by a NW-SE fault systems which is parallel to the easternmost graben of the Pantelleria-Rift System. According to House *et al* (1961), the throw along the northward dipping Victoria Lines Fault reaches up to 183m on the West coast of Malta, and reduces in height towards the east coast to about 90m.

Illies (1980) described growth faulting with a trend of 55°, south of Xlendi Bay on Gozo. He also portrayed the mechanism of the local graben systems suggesting any possible future movements which could occur. Illies (1980, 1981), made observations on other aspects, such as the decrease in thickness of the Lower Globigerina Limestone found towards the Comino

Channels (Pedley *et al.* 1976) which, according to him, is caused by a slight trending basin-and-range formation amid the Victoria Lines Fault. These are located in Central Malta and the South Gozo Fault. He also published a structural map giving special reference to features like collapse systems, sedimentary dykes, pop up features, growth faulting and feather faulting. However, Illies fails to explain in detail the structural occurrence of feather faults which was later done by Reuther (1983).

The most notorious young tectonic characteristic is the system of the Maghlaq Fault (Pedley and Waugh, 1976), South East of Ix-Xaqqa that is found along the southern coast of Malta with an upright displacement of at least 240m to the South West (House *et al.* 1962).

The Afro-Eurasian plate boundary where the Maltese Islands are located is featured by an active seismic belt, which extends from the Azores across Gibraltar and North Africa to Northern Sicily (McKenzie, 1970, 1972). The tectonics of the Mediterranean basin, which explain the faulting in the Maltese Islands, were described by Grasso *et al.* (1995). He gives an account on the tectonic history of the Mediterranean region from the Tertiary Period up until the present day. This is an essential and significant text as it describes all regional movements which took place during the creation of the Maltese islands.

## 3.8 Geology of the Maltese Islands

Geology was one of the focal issues to be dealt with while conducting this dissertation. This is because geology plays an important role in the shaping of the coast itself. Geology may be divided into three categories:

- Lithology - is essential when discussing erosion caused by water, as it includes features such as the permeability of the rock, which determines the susceptibility to erosion;
- Aspect – determining the condition of the rock and the coastal stability ;
- Tectonics - may weaken the coastal zone making it more easily erodable.

The Geology of the Maltese Islands has been studied by various scientists and the subject is considered to be well documented. The first known study on the geology of the Maltese Islands was done by Spratt (Spratt and Forbes, 1843; Spratt, 1852), followed by many others including: Adams (1864, 1870, 1879), Murray (1890), Cooke (1893, 1896), Rizzo (1914, 1932), Trechmann (1938), Reed (1949), Hyde (1955) who reviews earlier literature on Maltese geology, House *et al* (1961) who on the other hand gives more modern general accounts, Vossmerbäumer (1972), Felix (1973), Pedley (1976, 1978, 1985), Davies (1976), Zammit Maempel (1977), Challis (1979), Drooger (1985) and Alexander (1988). When taking into consideration all the above mentioned studies, Pedley and Zammit Maempel seem to give the more popular and more contemporary outline of the geology of the Maltese Islands.

The lithostratigraphy of the Maltese Islands has been renowned since the time of Spratt (1843) owing to the simplicity in its structure. Spratt (1867) was the earliest scientist to publish

on the Quaternary geology followed by a more detailed study by Trechmann (1938). Spratt (1843) was also the one who recognized the *Scutella* bed which marks the top of the Lower Coralline Limestone. The terminology used nowadays to denote the individual formations, originated from the work of Murray (1890) but Cooke (1893, 1896) gave further details on the Globigerina Limestone and Blue Clay.

Rizzo (1932, p.12) was the first to suggest that Globigerina Limestone should be subdivided into Lower, Middle and Upper divisions. He prepared a geological map to demonstrate these outcrops along with his own *Report on the Geology of the Maltese Islands* (1932) but this was never published. Felix (1973), and Gianelli and Salvatorini (1975) improved the biostratigraphy, while Pedley *et al.* (1976) provided interpretative work on the paleoenvironment.

UPPER CORALLINE LIMESTONE FORMATION up to 162m		TORTONIAN	MIOCENE
GREENSAND FORMATION 0-12m		SERRAVALLIAN	
BLUE CLAY FORMATION 0-65m		LANGHIAN	
GLOBIGERINA LIMESTONE FORMATION 23-207m	UPPER <i>UPPER PHOSPHORITE</i>	BURDIGALIAN	
	MIDDLE <i>LOWER PHOSPHORITE</i>		
	LOWER	AQUITANIAN	
LOWER CORALLINE LIMESTONE FORMATION over 140m		CHATTIAN	OLIGO- CENE

**Table 3.2: Mid-Tertiary Rock succession for the Maltese Islands, lithostratigraphy**  
**Mainly after Murray (1890), chronostratigraphy after Felix (1973). From Pedley *et al* 1978.**

Hyde's *The Geology of the Maltese Islands* (1955), gave the first general detailed account of the Maltese geology. His main intention was to explain the range of elements which have been the key to giving the shape of Malta as we know it today. He explains the Islands' stratigraphy with reference to palaeogeographical and lithological factors.

Pedley (1976, 1978, 1985) has done thorough and detailed geological work/ Perhaps it can be said that he was the person who played the most important role in the geology of the Maltese Islands by contributing the most to the geological knowledge. He improved further and explained the two Coralline formations from the lithostratigraphic and paleoecologic aspects. He documented the thickness of various limestone sections in order to understand better the structural geology of the Islands.

Research on weathering of our limestone rocks, especially that of Globigerina Limestone, was done by the Institute of Masonry and Construction. Such research was done by Cassar (1999, 2002).

### **3.9 Geomorphological mapping**

Another aspect which this dissertation focuses on is Geomorphological Mapping. The internet was used to get a basic idea of symbols used when mapping and also to get advice from experienced mappers, on how to go about constructing a map. This included what type of data should be collected when on the site such as: measurements, the right angle from which pictures should be taken and other useful suggestions which helped during the field site visits.

Geomorphological mapping takes into consideration one of a group of techniques under the vast category of terrain evaluation. This is utilized to record systematically the shape (or morphology), the landforms, landscape-forming processes and materials that make up the surface of the Earth. Lee (in Sunamura, 1992) distinguishes three types of geomorphological maps:

1. *Regional surveys of terrain conditions, either for land use planning or in baseline studies for environmental impact assessment.*
2. *General assessments of resources or geohazards at scales between 1:50,000 and 1:10,000.*
3. *Specific-purpose large-scale surveys to delineate and characterize particular landforms.*

(Lee in Sunamura, 1992 )

Standard symbols to be used on geomorphological maps are enclosed in Cooke and Doornkamp (1990) with Demek and Embleton (1978) providing a more comprehensive collection of symbols that allow subtle differences to be highlighted.

# **Chapter 4**

## **FIELDWORK METHODOLOGY**

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## 4.1 Overview

This chapter deals with the methods and techniques used during the fieldwork pertaining to this dissertation. It involves surveys, which were conducted on the field. Such surveys included: sediment analysis, wind direction analysis, wave movement and also the noting and measuring of rock surface discontinuities and fissures. These however, only reveal information on short term coastal erosion. Maps, aerial and ground photographs are what gave a long term idea of coastal erosion in the studied area. These were observed in great detail to produce my own thematic maps showing erosional and depositional processes which were observed throughout all the research conducted. Two main computer software programs were used as an aid for the production of the maps. ArcGIS and C-Map World. A Geographic Mapping System (GIS) is a full-features mapping system where the data are linked in a two-sided manner to an internal database management system (Poizner, 1992 in Green, D., Rix, D., Corbins, C. 1997). This is what in actual fact helped in producing maps and analyzing them further. C-Map World, which in reality is a software used by mariners, gives the water depth as well as other useful information, such as fuelling sources and the location of light houses and light buoys while in this case it was used to observe the bathymetry of the area.

## 4.2 Identification of aim and data collection

The focus of this study is to analyze the geomorphological features present in the area of Xrobb-Ghagin. This research attempts to answer three main research questions.

1. Whether geology effects the geomorphological landforms present in the area of study.
2. Identifying the major factors which have affected erosion in the area of study.
3. Whether aspect has an effect on the area of study.

Due to the absence of any secondary geographical data on the area, apart from photographs, information could only be obtained by carrying out fieldwork sessions on site. The first set of field studies were aimed mainly at observing the area. This was done in order to become familiar with the area, find paths through which the bay could be accessed safely and jotting down a list of geomorphological and man-made features which can be found in the area. Other fieldwork were carried out later when a number of photographs of the area and mainly of geomorphological features present were taken, and during the following months, the required data needed to create the geological and geomorphological map were collected.

Before conducting the last four fieldwork sessions , a base map was obtained from the Mapping Unit and three extra copies were made in order to have a rough and a final copy of both the geological and geomorphological map.

### 4.3 Dissertation Time-Line

<b>March</b>	<b>Propose title</b>
<b>April</b>	<b>Abstract</b>
<b>May</b>	<b>Poster</b>
<b>June</b>	<b>Find general information about the area and coastal geomorphology</b>
<b>July</b>	<b>Field sessions: site observation and photographs</b>
<b>August</b>	<b>Research</b>
<b>September</b>	<b>Research</b> <b>Field sessions: list geomorphological features</b>
<b>October</b>	<b>Literature Review</b>
<b>November</b>	<b>Literature Review, Introduction,</b>
<b>December</b>	<b>Introduction to Geology and Coastal Geomorphology of the Maltese Islands</b>
<b>January</b>	<b>Field Sessions: Mapping and photographs</b>
<b>February</b>	<b>Field Sessions: Mapping</b> <b>Methodology</b>
<b>March</b>	<b>GIS Mapping</b> <b>Analysis</b>
<b>April</b>	<b>GIS Mapping</b> <b>Conclusion</b> <b>Proofreading</b>

Table 4.1: Time-line followed during the creation of the dissertation

Table 4.1 provides a time-line which was followed when researching and writing the dissertation. This time-line was considered necessary because time is in itself a very important factor when studying geomorphology and has to constantly be kept in mind in order to understand better the dynamics of erosion.

In order to have clearly defined rates of erosion, a study has to be done on a much longer period of time. However, changes in the area of study were noted even during the short period of observation. Changes were in fact very evident when considering mass movement factors. Cliff faces which seemed unstable on the first visit to the area were not visible any more and instead, there was an increase in the sediment lying below the same area. This implies that, that which in the first field session was unstable had been broken off and deposited at the bottom of the cliff in the form of large rocks, pebbles and silt.

The time factor was also the reason why writing each chapter of the dissertation followed the above sequence.

## 4.4 Geological Mapping

A geological map is very often considered as a way to familiarize oneself with the geology of an area, (Maltman, 1992). The geology of the field site was mapped with reference to the *Geological Map of the Maltese Islands (1993)*. Given that this was considerably accurate in the area of study, irrespective of its small scale (1:25 000), it was decided to maintain the data given by this map and revising it through the field sessions and aerial photograph. The aerial photographs of the area were obtained from Malta Environmental and Planning Authority (MEPA).

In order to create the geological map, a number of sources were consulted, namely Barnes (1991) and Maltman (1992). These discuss very specifically the methods that should be used to create an accurate and detailed geological map. This literature was useful in assessing whether features should be added to the *Geological Map of the Maltese Islands (1993)* or not.

### **Step 1**

A topographic map was obtained from the Mapping Unit on which the geology of the site was drawn.

### **Step 2**

With the help of aerial photographs which were obtained from Malta Environmental and Planning Authority (MEPA) it was possible to become familiar with the forms and features of the area before and also during the making of the geological map on site.

### **Step 3**

Following the *Geological Map of the Maltese Islands (1993)* the surface geology was observed, plotted and some more features which were noted on site were added and others corrected. This was for the reason that in some places the change between Middle Globigerina Limestone and Lower Globigerina Limestone was not exact, but changes were in fact minimal.

### **Step 4**

A fair copy was produced. The position of faults and dips in the area of study was not measured on site but noted from the *Geological Map of the Maltese Islands (1993)*. These were added to the neat copy.

### **Step 5**

The fair copy was reproduced using GIS. This map was scanned and through a long process, made to overlap the topographic base map provided on GIS. This was done to make the map as accurate as possible by following the exact lines and location of the geological features. The map can be seen in Figure 5.1 and 5.2.

### **Step 6**

All the geological formations present at the studied field were listed and described. The characteristics of each geological feature were inserted into Table 5.1.

## 4.5 Geomorphological Mapping

In order to identify the main coastal landforms present in the area of study, a coastal geomorphology survey had to be done and the creation of a geomorphological map followed this survey. Geomorphological maps include information on the morphology, origin and age of landforms. These mark the presence of key features in the landscape, and portray certain attributes. The modern detailed geomorphological map offers a unique means of displaying all of the various factors and features of the physical landscape in a systematic scientific fashion. Such a map is the main analytical research instrument developed so far by which it is possible to approximate a portrayal of the Earth's complex surface and its dynamics.

The production of geomorphological maps starts with aerial photography and ground survey. Photography can enable the creation of a base map which is later 'ground truthed' in the field. Ground truthing is a critical part of the process. This is because small scale features can often be missed, and larger scale features can be misinterpreted.

(<http://www.staffs.ac.uk./schools/sciences/geography/staff/harrist/landev/lect15notes.htm>)

In order to create an accurate geomorphological map it was necessary to adopt the mapping steps, which were available on the website as the main method.

### **Step 1**

A copy of the topographic base map was used to map the geomorphological features present on site. Here both the landforms and the factors which may have an affect on the geomorphology of the area were mapped. Such factors are fields, roads, paths and water courses.

## **Step 2**

The aerial photographs obtained from MEPA were a main tool in the process of geomorphological mapping. An initial copy map was created according to the aerial photographs.

## **Step 3**

Ground truthing was carried out on site in order to verify the geomorphological map created previously through the observation of the aerial photographs.

## **Step 4**

A fair copy of the map produced on site was made.

## **Step 5**

Using GIS, a computerized copy of the geomorphological map was created. This can be seen in Figure 5.3.

## **Step 6**

The landforms and features mapped were listed and described in Chapter 5.

## **Step 7**

One particular area where geomorphological landforms were abundant, was further studied creating a more specified map in order to represent these features. This can be seen in Figure 5.7.

## **4.6 Classification of Landforms**

Classification is the grouping of similar features in classes that are contrasted with other dissimilar features (Bird, 2001). Classification of rocky coastal on the basis of geology and structure was advocated by Russell (1967). Limestone coasts have a distinctive kind of coastal landforms, with contrasts related to structure, wave energy and weathering regimes. (Bird, 2001).

Clark (1985 in Magri, 1995: 12; Caruana, 2006: 37) defines classification as the:

*“...arrangement in classes, or putting into groups systematically, on the criteria of common characteristics or properties.”*

In consideration of the hypothesis of this study which focuses on the geology and coastal processes resulting from wave action present at the field site, two coastal classifications were created following Bird's (2001) examples. These are:

1. Geology in Coastal Classification
2. Classification based on Coastal Processes

The geological and Geomorphological maps produced provide the basis for a coastal classification based on the geology of the area. On the other hand, a coastal classification based on coastal processes which occur at rocky coasts, were figured out. The results of this classification are shown in Table 5.1.

## **4.7 Conclusion**

A proper methodology was necessary to be able to study the field, carry out the surveys and drawing maps as accurately as possible. The methodology was needed as a manner to obtain all the information. It provides each step taken while carrying out the practical work of this study. The drawing of the maps was done step by step as are illustrated above. These steps were found to be very useful while drawing the maps and were followed in the sequences suggested. This task of creating the geological and geomorphological maps could not have been carried out without the help of aerial photographs and the numerous field visits.

# **Chapter 5**

## **ANALYSIS AND RESULTS**

---

## 5.1 Overview

This chapter deals with the results and their analysis following the field sessions. Here a clear and detailed explanation of all the geological and geomorphological features found on site is given, clarifying the reasons for the presence of each feature in the area of study. The maps which were created are included in the chapter in order to illustrate the location of each feature in the area.



**Plate 5.1: Aerial photograph of the area of study**

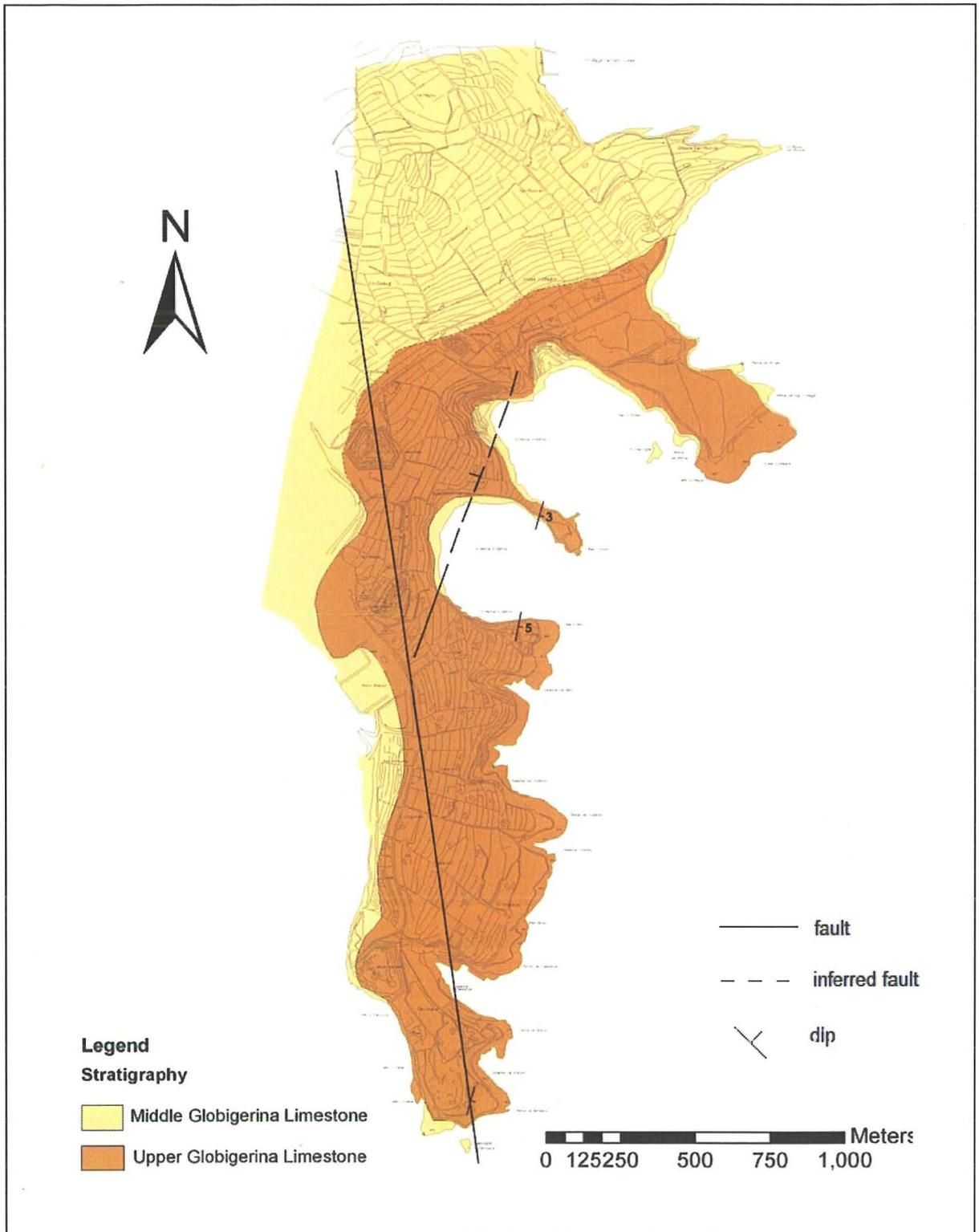
## 5.2 The Geology of the Field Site

Figure 5.1 shows the geological formations and structures which can be found at the whole area of Delimara. According to Figure 5.2, which specifies in more detail the geology of the Xrobb l-Ghagin area, shows that the geological formations present in the field site are Upper Globigerina Limestone and Middle Globigerina Limestone. These formations are both very vulnerable to the erosion and weathering processes mentioned in Chapter 3. Namely these are abrasion, hydraulic pressure, attrition, corrosion and salt weathering.

The geological structures were based upon those provided by the *Geological Map of the Maltese Islands (1993)*. Figure 5.1 shows that the geological structures present on the field site and its vicinities are:

1. Faults
2. Dipping strata with direction and inclination in degrees

Figure 5.1: GEOLOGY OF DELIMARA AREA



Source: Based on Geological Map of the Maltese Islands (1993)



### 5.2.1 Faults

A fault is a fracture or zone of fractures between two blocks of rock. Faults allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake - or may occur slowly, in the form of soil creep. Faults may range in length from a few millimeters to thousands of kilometers. Most faults produce repeated displacements over geologic time. Faults can be considered as structural discontinuities.

Although the faults found on site were mapped according to the *Geological Map of the Maltese Islands (1993)*, faults could be noticed on site through the observation of the changes in the topography on either side of the fault itself. The aerial photographs also show these faults rather clearly.

Barnes (1991) suggests that most fault zones are more susceptible to erosion and therefore erode faster than their surrounding rocks and hence leading to the formation of longitudinal depressions.

According to Bird (2001:91) "*Quarrying by waves can dissect shore platforms, especially along joints or faults...*" Bird also sustains (2001) that plunging cliffs may also be a result of recent faults.

*"Plunging cliffs can be produced by recent faulting, the cliff face being the exposed plane of the fault on the up-throw side, the down-throw block having subsided beneath*

*the sea, there having been insufficient time for marine erosion to cut a shore platform at present sea level.”*

### **5.2.2 Dipping Strata**

Lisle (1988) suggests that dipping strata occur when bedding and other geological layers and planes are not horizontal. A dip is the angle of tilt, measured in degrees below the horizontal while the direction of dip is the direction towards which the surface is inclined (Barnes, 1991).

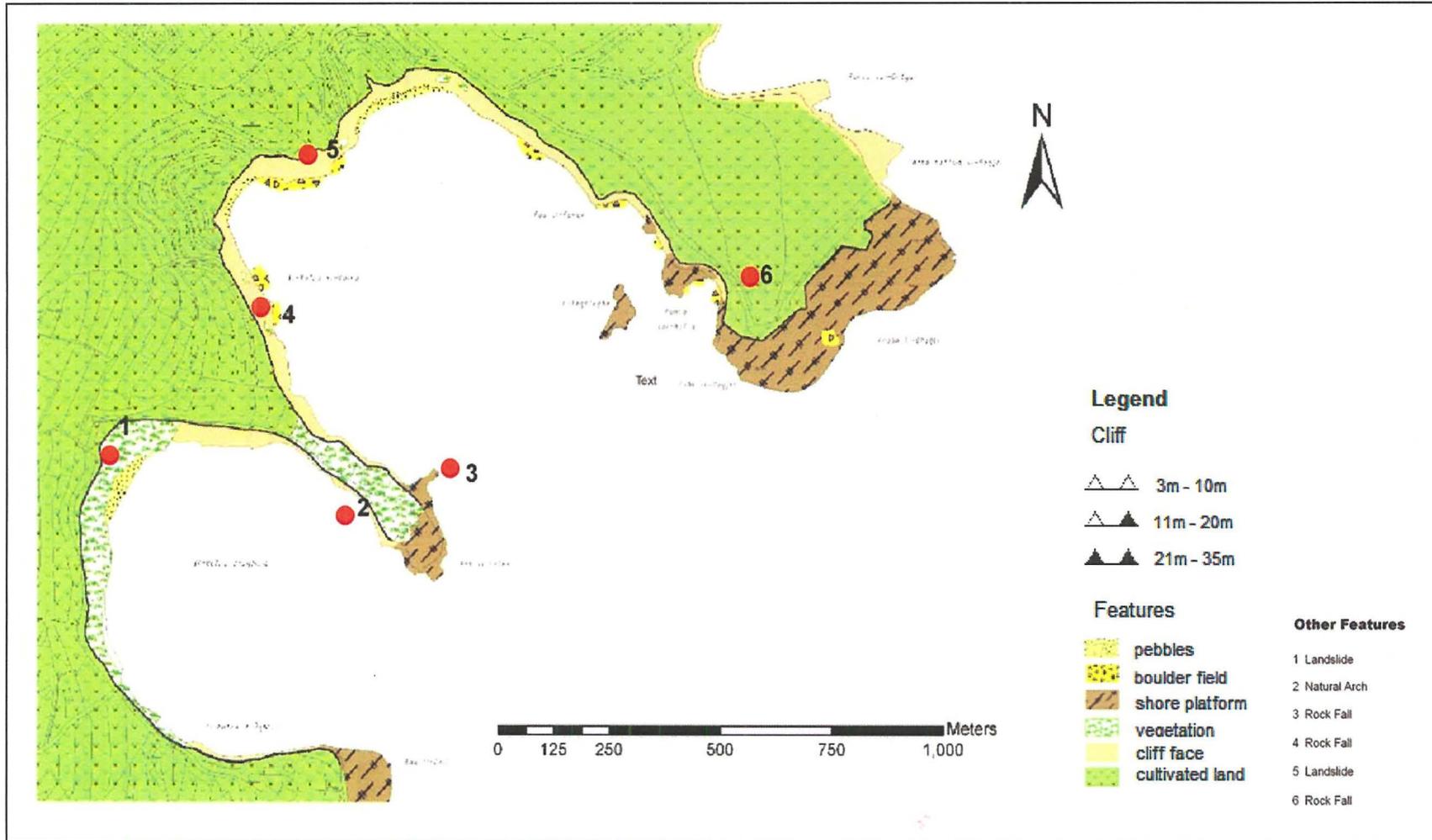
At the field site, dips were found in the Upper Coralline Limestone formation. The degree of the dip at Ras il-Fenek is 3°, while the next dip further south at the other side of Il-Hofra iz-Zghira is of 5°, therefore both these are near horizontal dips. These can be clearly seen in Figure 5.2.

## 5.3 The Geomorphology of the Field Site

Figure 5.3 shows the landforms which are present at the field site. Here is a list of coastal landforms which are present at the field site according to Figure 5.3. These are further explained later on in the chapter.

1. Upper Globigerina Limestone Sloping Cliff
2. Rock Fall
3. Boulder scree
4. Pebble beach
5. Natural Arch
6. Middle Globigerina Limestone Stump
7. Middle Globigerina Limestone Shore Platform
8. Potholes
9. Notch

Figure 5.3: GEOMORPHOLOGY OF XROBB L-GHAGIN



Source: Developed by author following field investigation

## 5.4 Explanation of Landforms

### 5.4.1 Shore Platform/Wave Cut Platform:

The shore platform in the Xrobb l-Ghagin area seemed to be a very prominent and important feature to which several other features such as potholes, rock fall, pebble beaches and even the stack seemed to be correlated. This is located in the Northern part of the area of study being strongly hit by South Easterly winds. This area was in fact studied in further detail primarily to have a better description of all the present features as well as to understand the relationship between all the geomorphological landforms which are found in such a small area and in many ways, seem to form part of the same system.

Shore platforms as a general definition, are rock surfaces created by the erosion and retreat of coastal cliffs. According to Trenhaile (in Goudie, 2004b) it is evident that

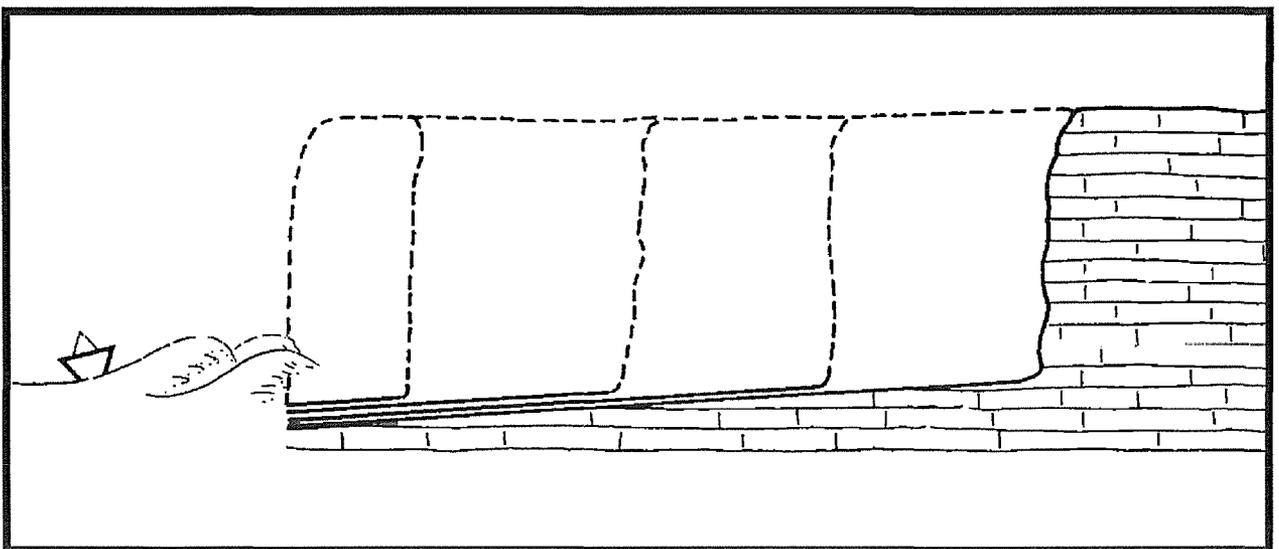
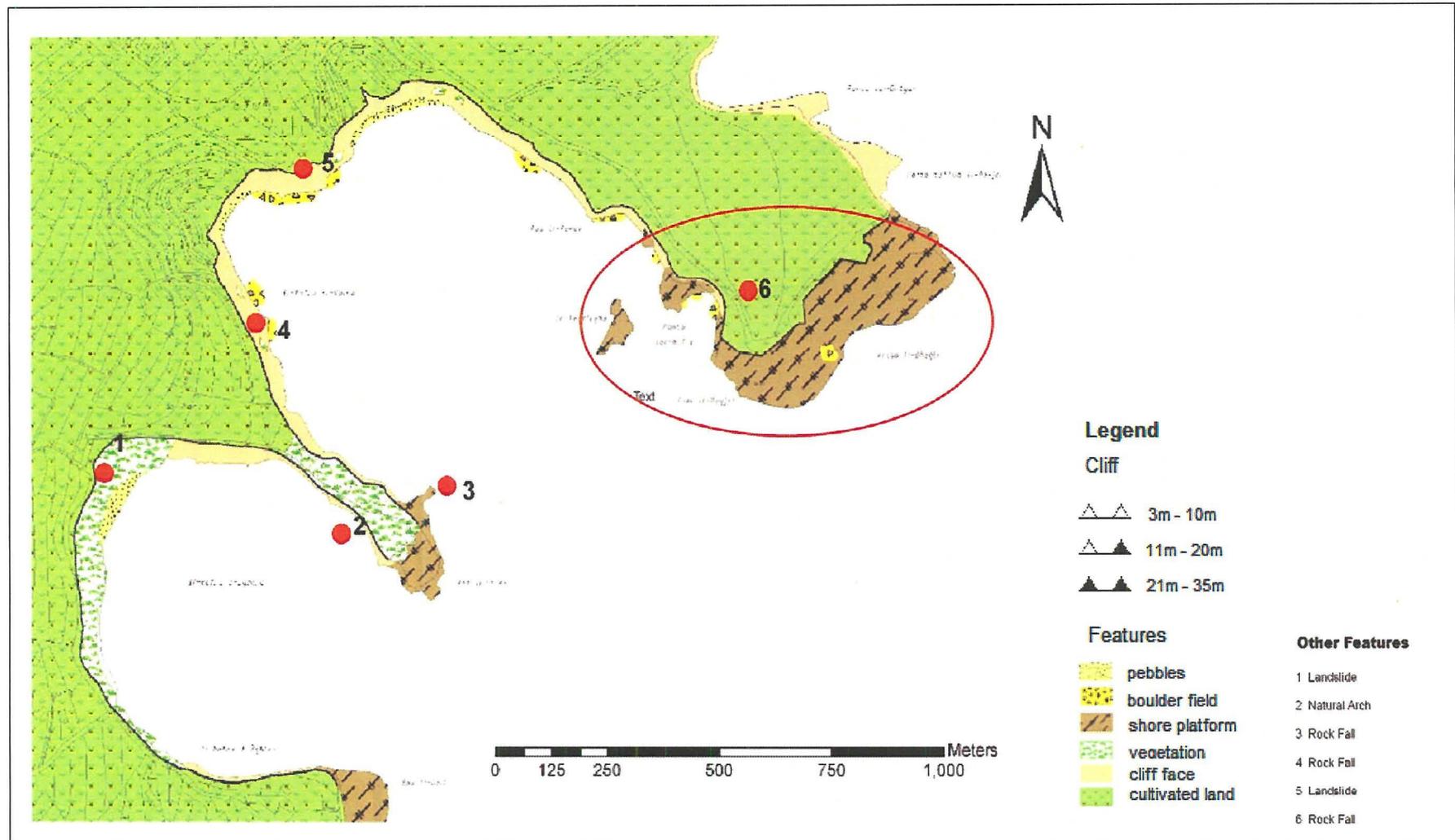


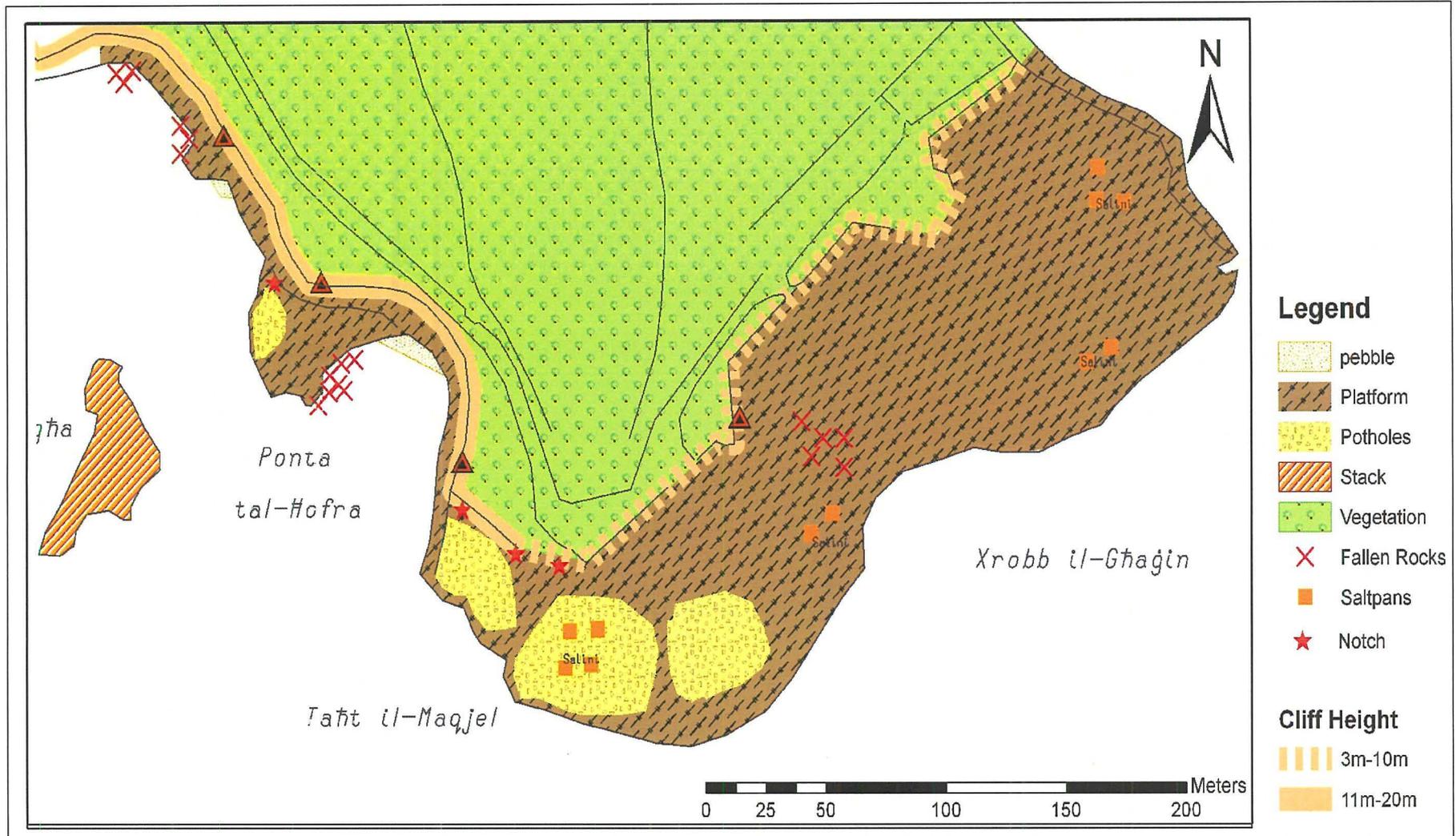
Figure 5.4: A sketch showing the formation of a shore platform  
Source: Panizza, M. 2005

Figure 5.5: FOCUS ON SHORE PLATFORM



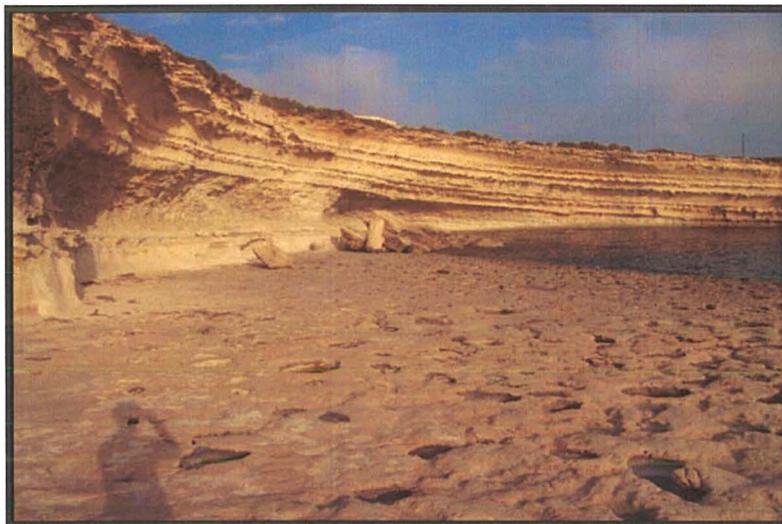
Source: Developed by author following field investigation

Figure 5.6: THE SHORE PLATFORM



Source: Developed by author following field investigation

shore platforms are produced by mechanical erosion, wave erosion, weathering and bioerosion. Trenhaile (in Goudie, 2004b) also suggest that the importance of the above depends upon the climate, geology, wave and tidal conditions along with the stage of development of the area. There may be different types of shore platforms along the same coastline. This difference all depends on the geology, aspect and the morphogenic factors, such as tidal range and wave regime which affects each and every cliff face differently (Bird, 2001).



**Plate 5.2: Shore platform at Xrobb I-Ghagin**

The term 'Shore Platform' is preferred to the older term 'wave-cut platform' as the latter implies that the development of the platform was produced by one single process. It is also thought that in some cases these were inherited from previous sea levels and therefore having been formed thousands of years ago.

Paskoff and Sanlaville (1978) suggest that the shore platforms found on the island of Gozo are a product of relatively recent processes which developed at today's sea level.

Figure 5.8 shows the characteristics of the shore platform present in the area of study

Different coastal processes bring about different types of platforms. Sunamura (1992) and Bird (2001) identify two types of shore platforms which are relevant to the study:

1. Gently sloping shore platforms without a significant topographic break, extending from the base of a cliff to the nearshore sea floor below low tide level. These are known as Type A and are said to have been shaped mainly by wave abrasion with minor contributions from weathering, bioerosion or solution processes.
2. Type B shore platforms are nearly horizontal platforms with a very gradual seaward slope usually of less than  $1^\circ$ . These usually end abruptly seaward in a steep drop known as the low tide cliff. Type B shore platform is also known as 'high tide platform' as they develop at, or slightly above the average high tide level.

Considering the explanations given by Sunamura (1992) and Bird (2001), it can be assumed that the shore platform present at the site studied is in fact a Type A shore platform having a gradual gently sloping shore platform. This can be seen in Plate 5.2 and mapped in Figure 5.7.

### **5.4.2 Potholes:**

Along the shore platform mentioned above, several potholes were found along the seaward side. Potholes are vertical, circular and cylindrical erosion features which are almost symmetrical. There are generally formed on shore platforms mainly created by the grinding action of sand, gravel, pebbles and boulders which are moved or rotated under the energy of waves. According to Dionne J. C. (in Goudie, 2004b), these usually range between a few centimetres to a few metres in size. He also suggests that potholes are produced by abrasion, cavitation, dissolution and/or corrosion.



**Plate 5.3: Potholes along the seaward side of the shore platform**

### 5.4.3 Notch:

Several notches, where also noted both on the shore platform (Plate 5.4) as well as at the base the cliffs in the whole area of Xrobb l-Ghagin, most of these were in fact found on the North side of il-Hofra il-Kbira (Plate) whereas in il-Hofra iz-Zghira no notches were made note of. Commonly, notches can be found at the foot of a cliff, a platform or a reef flat. These are most common and best formed on tropical limestone coasts where the tidal range is minimal and therefore erosional processes are more concentrated on these areas. Notches usually range between 1 and 5 metres in depth and it is suggested that these are produced through agents such as beach material which work as an abrasive tool. The rate of the growth of the notch depends on the strength of the rock forming the cliff, the energy level of waves arriving at the cliff base. And the amount of abrasive material set in motion by waves at the cliff-beach junction. Figure 5.8 represents the formation of and the processes which follow a notch.

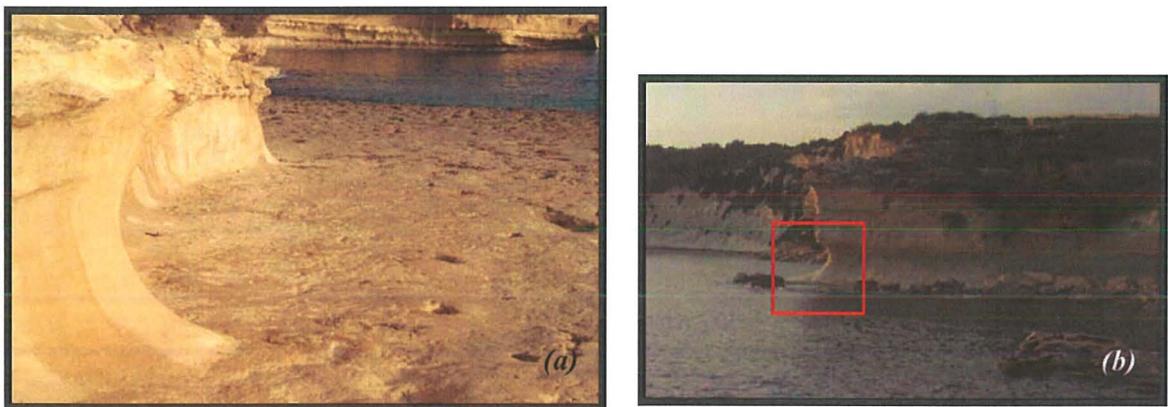
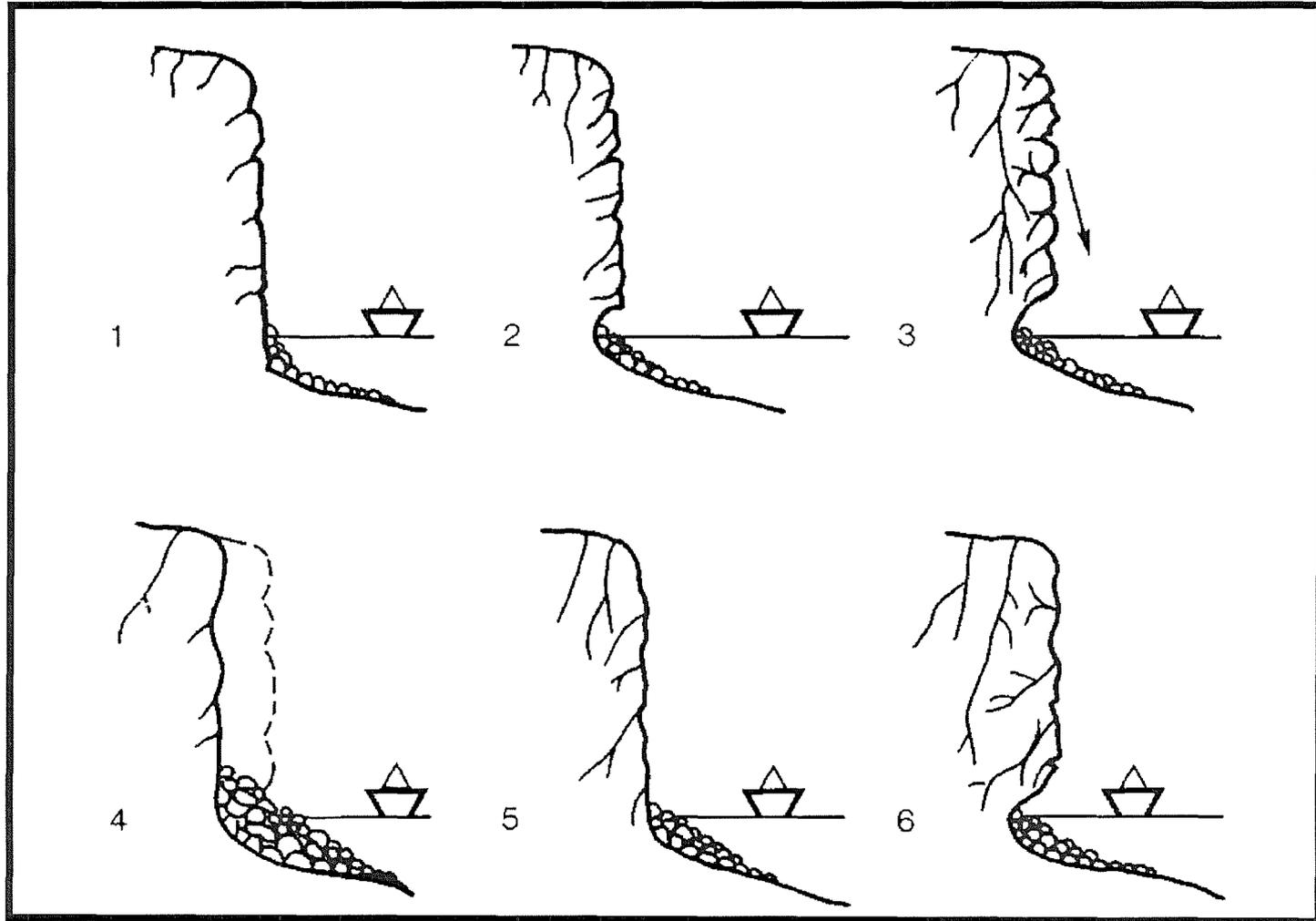


Plate 5.4: (a) a notch at the back of the shore platform; (b) a notches at the base of the cliff

Figure 5.7: Sketch showing the formation of a notch along a retreating cliff



Source: Panizza, M. 2005

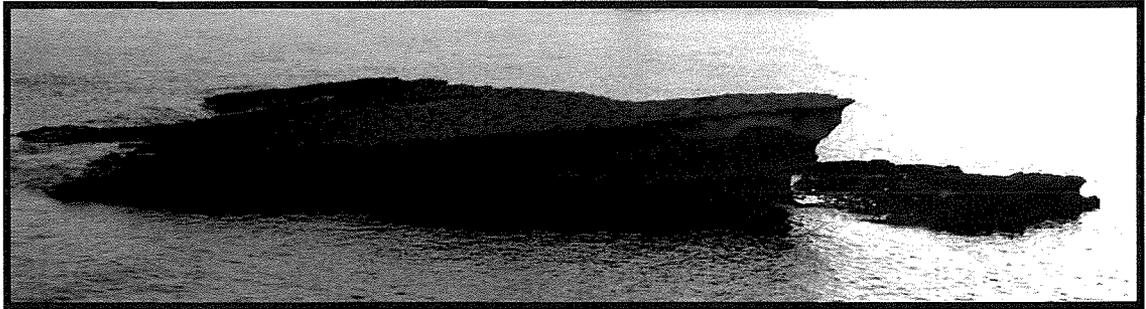
The mechanism of the formation of a retreating cliff can be simplified in the six stages shown in Figure 5.7.

1. Any type of cliff face in direct contact with the sea;
2. Erosional processes increase the size of cracks within the rock; the rocks and sediments at sea level which are in continuous contact with waves have an abrasive effect on the base of the cliff creating a notch;
3. The unsupported cliff above the notch topples into the sea;
4. Sediments which accumulate at the base of the new cliff face protect it for a period of time from erosional processes;
5. Sediments are eventually carried away due to wave erosion and persisting currents, consequently, erosional processes increase at the base of the cliff;
6. Erosional processes recreate another notch at the lower part of the cliff like in the morphological situation described in point 3. This cycle continuous and repeats itself over and over.

#### **5.4.4 Stack**

Just off the shore platform, a stump is found, this appears to be a small island, cut off from the main land by a few meters. This formation is known as a stump or an isolated shallow pillar of rock which forms when part of a retreating coast is separated from the mainland. In general, the shaping of stacks and later of a stump, is strongly influenced by weathering and erosional processes along steep or vertical joint planes, which thus dominate the bordering cliffs.

These occur either where the roof of a natural arch has collapsed or where a transverse inlet has been cut along a zone of weakness through the headland. In many cases as in the stump in discussion in the area of study, the stump seems to be inclined towards the seaward side. This is mainly because it is exposed to stronger wave erosion (Goudie, 2004b).

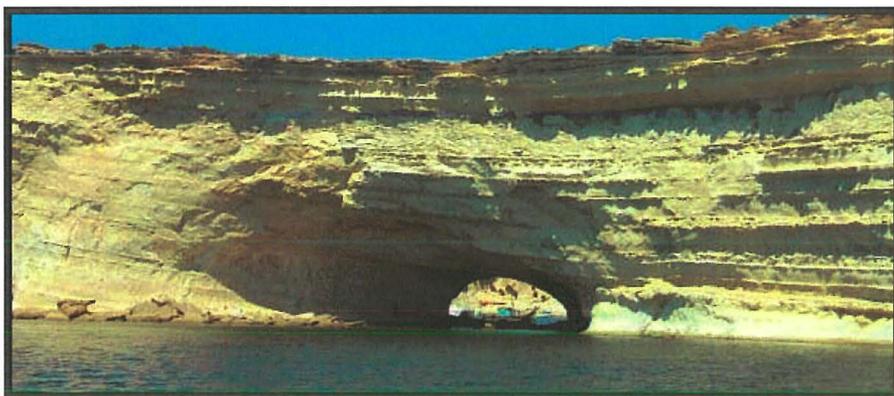


**Plate 5.5: Stack located at the field site**

Other features which have been described in other chapters were also present within the whole area of study such as cliffs and boulder screens. These clearly indicate that the area is very vulnerable to mass movement in this case, mainly to rock fall and slides.

### **5.4.5 Natural Arch**

The natural arch found in the area of study is seen as a major geomorphological feature. Natural arches are formed when weathering together with mass collapse, and in arid areas with wind erosion, creates a tunnel through a slab of rock. Arches are most numerous where long and closely spaced joints have been eroded to form narrow funnels of rock. These are readily pierced by weathering. Natural arches may take various forms but will remain stable provided the load is transmitted into the abutments. This condition is met so long as the thrust line of the load remains within the arch. Arches are therefore very stable features. However, continued erosion may result in an unstable form and the arch may then collapse by folding itself at several hinge points. Erosional weakening of the abutments into which the load is transmitted can also be cause an arch to collapse. (Young, R.W.). There are created where waves attaching either one or both sides of a promontary succeed in tunnelling a hollow completely through it, a sea arch is produced. Its formation is usually associated with a geological weakness. Collapse of the vault of the arch leads to the formation of a stack. Spectacular sea arches have attracted the attention not only of geomorphologists and geologist but also of tourists (Goudie, 2004b).



**Plate 5.6: Natural arch found on the field site**

## **5.6 Classification of Landforms**

Table 5.1 shows a division in the geomorphological landforms which are present in the area of study according to the geological structure. This also gives a clear illustration of what erosional factors helped in shaping each landform. Different landforms are in fact created by various erosional factors. Low-lying formations which were very close to the sea, such as the stump, shore platform and the notches, which in the case of this study occurred on Middle Globigerina Limestone, were more vulnerable to mechanical wave action, tidal change (although not very significant in the area of study), salt and chemical weathering. Other features such as the cliffs, slopes and to a certain extent boulder scree, apart from the above mentioned water induced erosional processes, these are also more exposed to physical and biochemical weathering as well as the gravitational downward pull creating a proneness to rock fall and slides. These were all located in areas made of Upper Globigerina Limestone and due to height, further away from the sea. It can be seen that both geology and distance have an impact on the geomorphological landforms and also on which erosional process act upon them.

According to geomorphologists and their theories observed in Chapter 3, South facing cliffs have sparse vegetation, with more surface run-off and wash erosion. Here one can generally find steep bedrock slopes. On the other hand North facing cliffs have a vegetated ground cover with gently slopes which are more susceptible to mass movement. This is due to deeper and highly water-infiltrated soils.

In the area of study, this proves itself very accurate. This is because the South facing cliffs are indeed sparsely vegetated with steep bare bedrock slopes while the North facing cliffs are mostly covered in vegetation with gentle slopes and prone to slides due to the high amount of

moisture in the soil. This in fact proves that in an area with so little human influence and where natural processes are dominant, aspect has a great influence on the geomorphological processes of the area. The difference in the intensity of the geomorphologic processes is indeed influenced by radiation.

**Table 5.1: Classification of the coastal landforms present at the field site on the basis of geology and coastal processes**

<b><i>Geological Formation</i></b>	<b><i>Landforms</i></b>	<b><i>Possible coastal processes which may be presently active on landforms</i></b>
<b><i>Middle Globigerina Limestone</i></b>	1. Shore Platform	Mechanical wave action, bioerosion, tide
	2. Potholes	Abrasion, salt weathering, chemical weathering
	3. Notches	Mechanical wave action, abrasion, hydraulic action, salt weathering, chemical weathering, rock fall and toppling
	4. Stump	Rock fall and toppling, mechanical wave action, abrasion, hydraulic action, physical weathering, salt weathering, chemical weathering, water-layer leveling
	5. Pebble Field	Mechanical wave action, bioerosion, hydraulic action, salt weathering, chemical weathering, rock fall and toppling
<b><i>Upper Globigerina Limestone</i></b>	1. Cliffs (5-35m above sea level)	Mechanical wave action, abrasion, hydraulic action, salt weathering, chemical weathering, rock fall and toppling
	2. Sloping Cliff	Biochemical erosion, slides, flows
	3. Boulder Scree	Mechanical wave action, bioerosion, hydraulic action, salt weathering, chemical weathering, rock fall and toppling
	4. Rock Fall	Physical weathering, salt weathering, biochemical erosion, biophysical erosion, human pressure
	5. Natural Arch	Rock fall and toppling, mechanical wave action, abrasion

**Source: Based on Paskoff and Sanlaville (1978); Rice (1985); Sunamura (1992); Bird (2001) and author's field observation)**



**Figure 5.8: Coastal Classification of Malta**  
 Source: Magri 1995

# **Chapter 6**

## **CONCLUSION**

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## **6.1 Overview**

This final chapter presents a concluding note to this dissertation. The chapter also gives some personal opinions about the findings as well as suggestion for future studies on this field. The main findings are to be found in sections 6.2, 6.3 and 6.4.

## **6.2 The Geological Map**

Figure 5.1 and Figure 5.2 show the geological structure of the field site. These are Upper Globigerina Limestone and Middle Globigerina Limestone. These show how both layers are very easily eroded especially Middle Globigerina Limestone due to its heavily jointed and fractured structure. The fault line that runs through both bays has been a cause for weakening in the area encouraging rock fall and slides.

## **6.3 The Geomorphological Map**

Figure 5.3 shows the landforms which were found on the field site. These were later explained and classified in Table 5.1. Figure 5.6 shows the geomorphological features located on the northern part of the site in more detail. This is where the shore platform, stump, potholes and other features are shown. This map was created due to a necessity to show further detail where so many features were located in such a small area. It is for the first time that a geomorphological map was made at such a detailed scale.

## **6.4 Results to the Research Questions**

The research which was carried out at Xrobb l-Ghagin turned out to be a very effective study in the field of geomorphology. The study, in fact, managed to reach a series of conclusions and also proved a number of hypotheses put forward before actually starting this research. These are:

1. Whether geology affects the geomorphological landforms present in the area of study.
2. Identifying the major factors which have affected erosion in the area of study.
3. Whether aspect has an effect on the area of study.

It has been proven that the geology may be a factor which affects geomorphological formations. This was seen in the various landforms of the two different types of rock present in the field. The short platforms were all found on Middle Globigerina Limestone; while cliff faces, slopes, arches and notches were found on Upper Globigerina Limestone. The effect of waves, salt

and water was much more prominent in the Middle Globigerina Limestone formation for it is much more exposed in direct contact to these erosional agents. Upper Globigerina Limestone, apart from these factors, is also influenced by biological and chemical agents.

As previously suggested from geomorphological text books, the aspect has a great influence on the shape, formation and even vegetation on each cliff face. This was clearly noticed when the area was represented on the maps. Here the difference between North facing and South facing cliffs was evident having vegetated slopes on the north-facing cliffs and steep and bare cliff faces on south-facing cliffs.

One of the more confusing aspects of coastal geomorphology is the extremely wide range of scale covered by the landscape. This includes small scale features such as potholes and large scale features in the configuration of the coastline itself, such as cliff faces which may cover much larger areas. These variations in the spatial scales are paralleled by changes in temporal scale. Time in fact is a very important factor when analysing coastal geomorphology. Our coastlines, as we know them today, were formed during the post-glacial periods which ended around 6000 years ago; while other features such as cliff retreat, mass movement and karstic formations have been created much more recently. The time factor was crucial in this research. Having held a very limited time frame in which the study was carried out, seasonal changes in geomorphological and geological aspects could not be compared to previously collected data by other researchers.

## 6.5 Further Research

In the course of writing this dissertation, the lack of work in the field of geomorphology in the Maltese Islands was very evidently marked. The necessity for more research in this field can be seen not just for the particular field site but for all of Malta especially in the Southern region. During the past 10 years a number of dissertations have in fact improved our knowledge of coastal geomorphology in the Northern coast of Malta and even that of Gozo however very little research has been made in the southern areas. Based on this fact, it would be a great gain if further geomorphological research on the Southern coasts of Malta was done. Several factors could in reality prove to good importance for environmental, infrastructural and economical purposes.

In the field studied in this dissertation, it was necessary to hold studies on a longer time span in order to have more representative results. More details on the rate of land slides could be obtained through this kind of study as well as observation of rock fall. An entire study could be made on the arch located between the two beaches in which the origin of this arch is studied as well as observation of the rates of erosion on this particular feature itself.

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# **APPENDICES**

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# ***Appendix I***



# ***Appendix II***

# Mass Movement

Mass movement, one of the most important geomorphological processes, is the down slope transfer of material through the direct action of gravity. Mass movement occurs when gravity overcomes the forces resisting it.

Several factors control the overcoming of inertia and causing masses of material to move downwards:

## 1. Effects of slope:

- The greater the slope, the greater is the shearing stress and, therefore, the greater the risk of slope failure.
- Planes of weakness are potential slide or failure planes.
- Slope may be over-steepened to unstable angles by erosion especially by undercutting
- Slope may be also destabilized but tectonic activity. This is most significant in young mountain ranges.

## 2. Effects of fluid:

- Increases in pore pressure in saturated rocks decreases the rock's resistances to shearing stress.
- The mass of the water added to regolith increases its weight and destabilised slopes.
- Water can seep between bedding planes in layered rock and reduce friction.
- Soils rich in clay absorb water readily and form weak gels which fail easily.

## 3. Vibration from earthquakes:

- Added stress may be as much as half that already present due to gravity.

- Ground shaking by earth tremors moves particles apart and reduces friction thus greatly increasing the risk of slope failure.

#### 4. Alternating freezing and thawing:

- Water seeps into the pore spaces between fragments of loose debris. As the water freezes it expands while when it thaws it contracts widening the pores.

#### 5. Effect of Vegetation Cover:

- Plant roots can form a dense interwinding network that binds loose soil particles and causes a flow.
- Vegetation also pumps water out of slope through evapotranspiration decreasing its strength.
- Vegetation normally increases slope stability but the added weight of the vegetation may destabilise a slope if the root network is limited.

#### 6. Quick clays:

- Are composed of rock flour of glacial origin which was deposited as sediment in marine environment. The resultant sedimentary rocks, therefore, contain salty pore water with the sodium chloride acting as binding agent.
- Fresh water flushes out the salt leaving honeycomb structures weakening the slope.

#### 7. Impact of human activities:

- Clearing of vegetation.
- Construction projects example: roads, quarrying and open-pit mining.
- Reservoirs greatly increase pore pressure behind dams. This increases risk of slippage.

Mass movement, one of the most important geomorphological processes, is the down slope transfer of material through the direct action of gravity. Mass movement occurs when gravity overcomes the forces resisting it.

Several factors control the overcoming of inertia and causing masses of material to move downwards:

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#### 9. Effects of fluid:

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- The mass of the water added to regolith increases its weight and destabilised slopes.
- Water can seep between bedding planes in layered rock and reduce friction.
- Soils rich in clay absorb water readily and form weak gels which fail easily.

#### 10. Vibration from earthquakes:

- Added stress may be as much as half that already present due to gravity.

- Ground shaking by earth tremors moves particles apart and reduces friction thus greatly increasing the risk of slope failure.

#### 11. Alternating freezing and thawing:

- Water seeps into the pore spaces between fragments of loose debris. As the water freezes it expands while when it thaws it contracts widening the pores.

#### 12. Effect of Vegetation Cover:

- Plant roots can form a dense interwinding network that binds loose soil particles and causes a flow.
- Vegetation also pumps water out of slope through evapotranspiration decreasing its strength.
- Vegetation normally increases slope stability but the added weight of the vegetation may destabilise a slope if the root network is limited.

#### 13. Quick clays:

- Are composed of rock flour of glacial origin which was deposited as sediment in marine environment. The resultant sedimentary rocks, therefore, contain salty pore water with the sodium chloride acting as binding agent.
- Fresh water flushes out the salt leaving honeycomb structures weakening the slope.

#### 14. Impact of human activities:

- Clearing of vegetation.
- Construction projects example: roads, quarrying and open-pit mining.
- Reservoirs greatly increase pore pressure behind dams. This increases risk of slippage.

## **Mass movement – Types**

A Rockfall is the free fall of rock from steep cliffs. It is the rapid downslope movement of rock material along a bedding plane, joint, or other plane of structural weaknesses. In the Maltese islands this usually occurs along fractured globigerina and coralline limestone walls. It may also be seen where greensands present a steep weathering face.

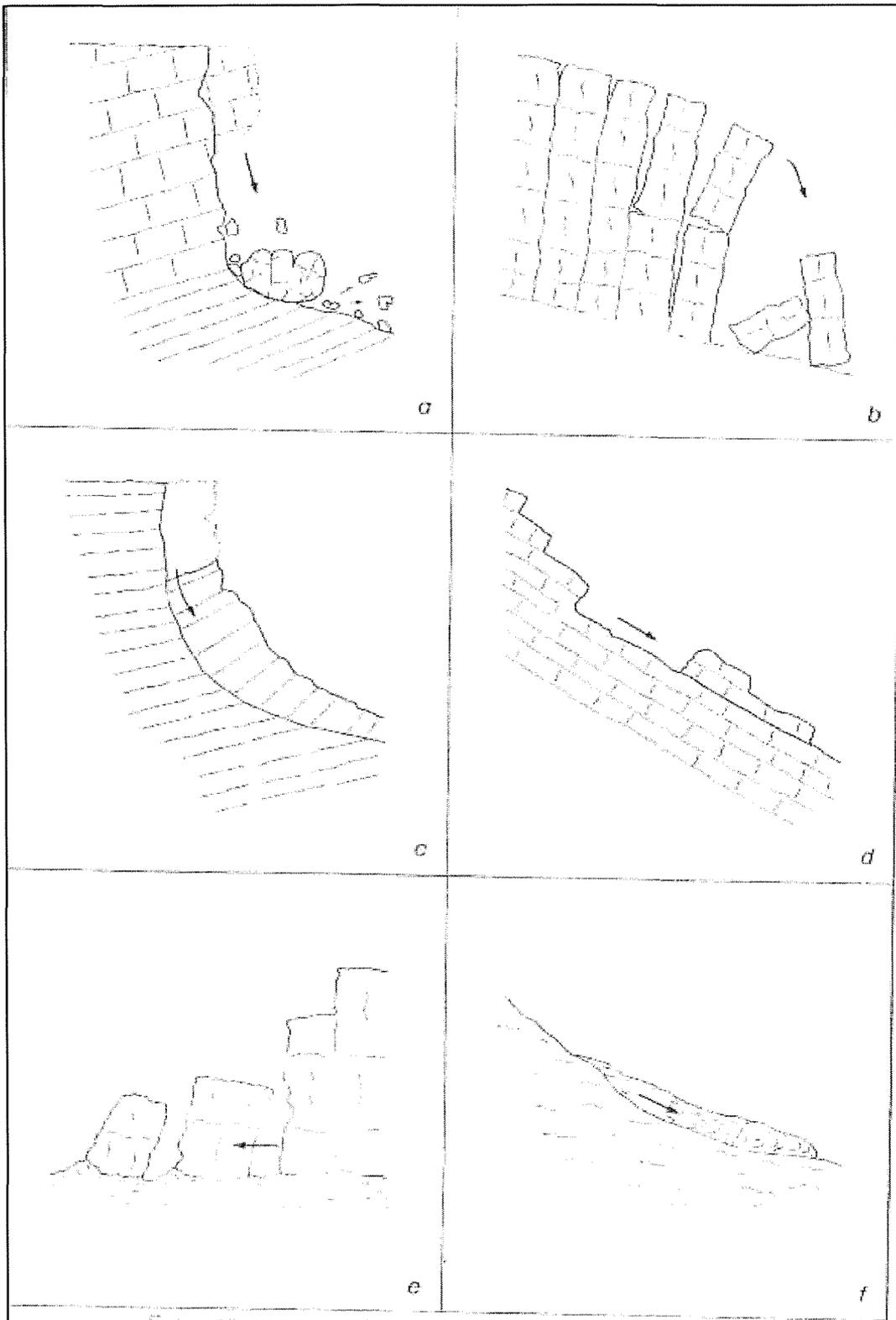
A Debris Slide is the rapid movement of soil and loose rock fragments. The mass can be dry or moderately wet.

A Debris Flow is the rapid flow a mixture of rock fragments, soil, mud and water. The mixture generally contains a large portion of mud and water.

Creeps are the slow downslope migration of soil and loose rock fragments resulting from a variety of processes, including frost heaving.

A Block Slide is the slow movement of large blocks of material over a layer of weak, plastic material (such as clay or shale). This is the process which creates Maltese Rdm coastline.

## Examples of Mass Movement types

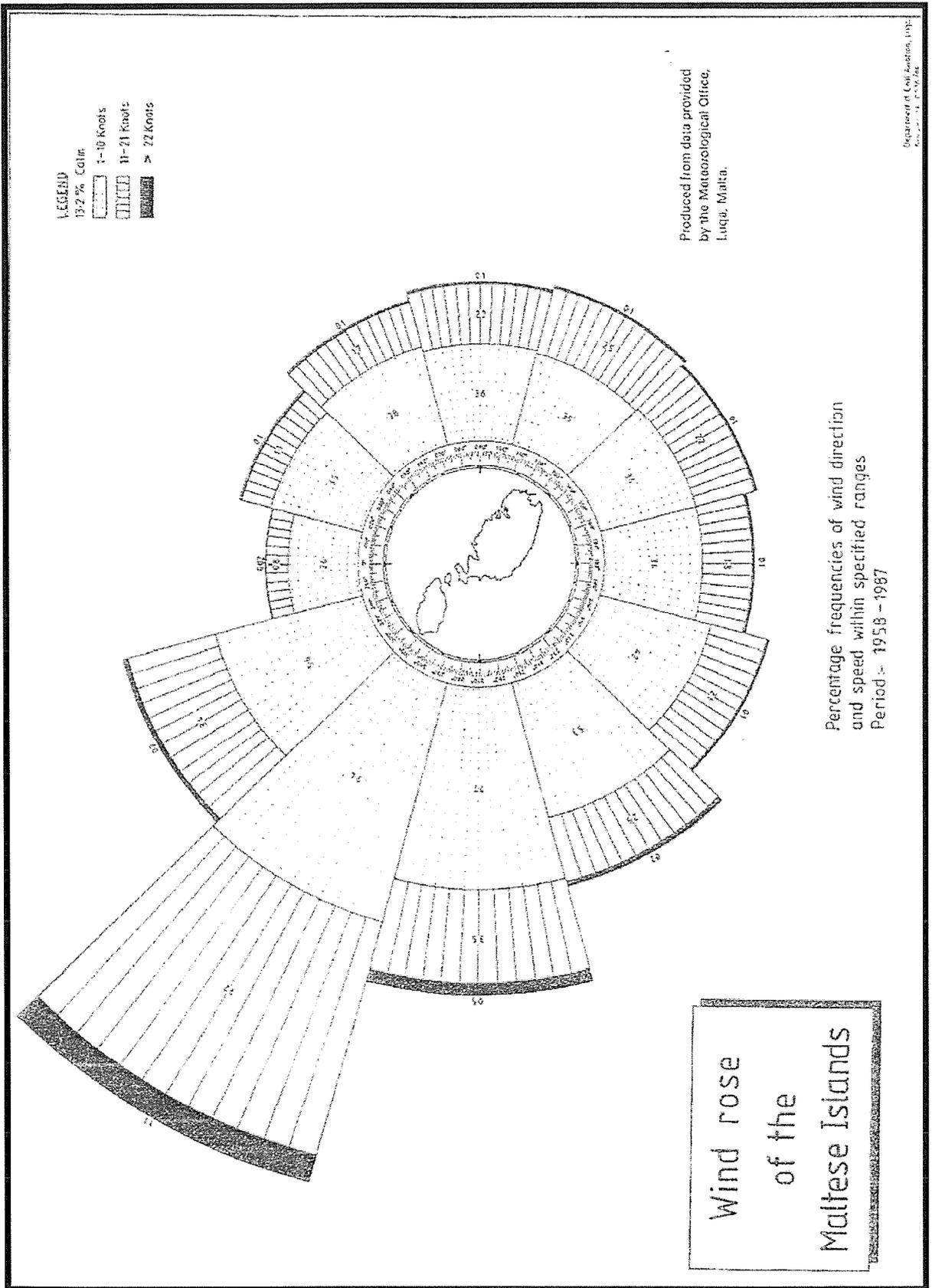


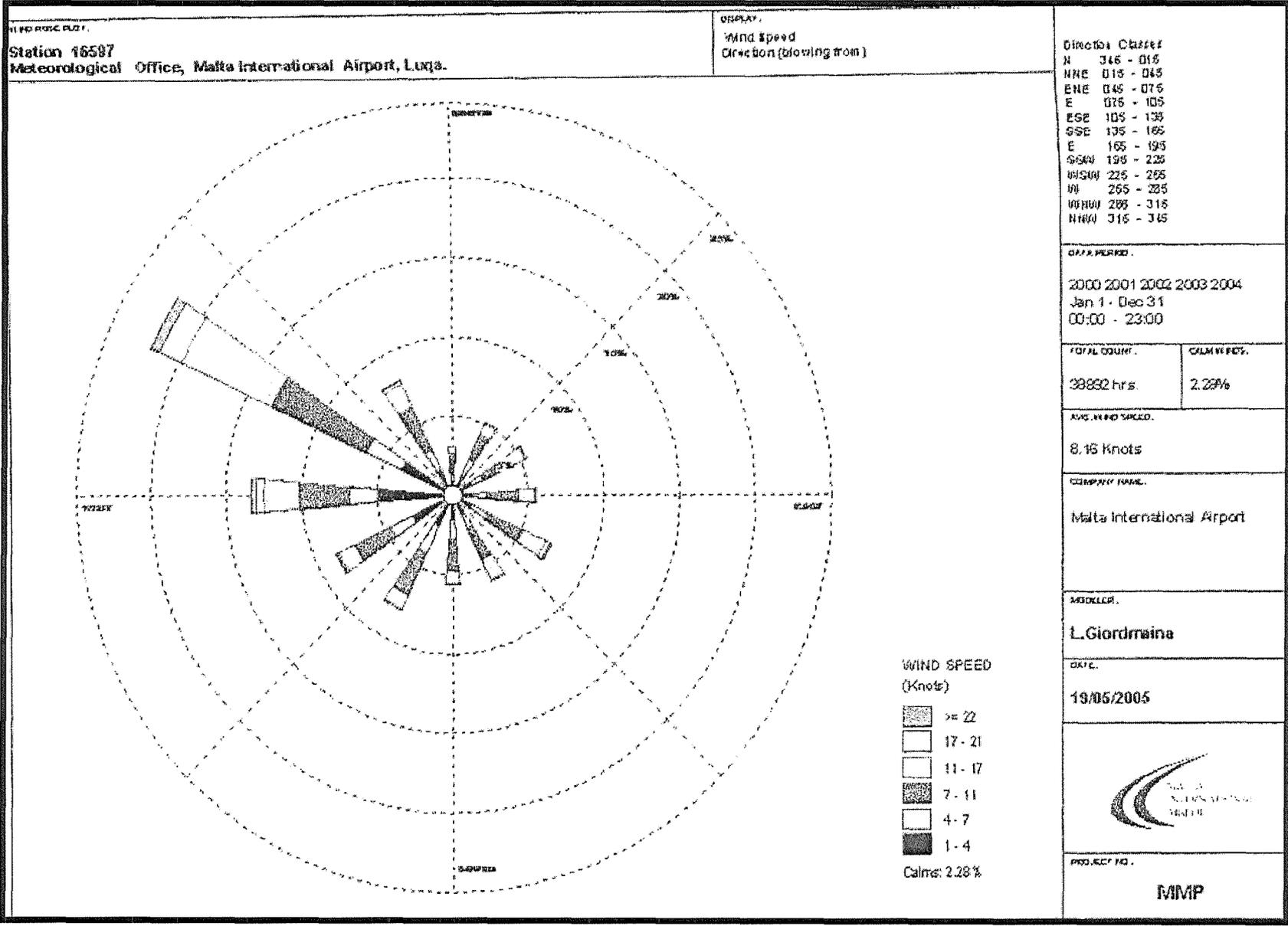
a) Rock fall; b) topple; c) rotational slide; d) translational slide; e) lateral spreading; f) flow.

Source: Panizza, M, 2005

# ***Appendix III***

# Meteorological data: 1958-1987

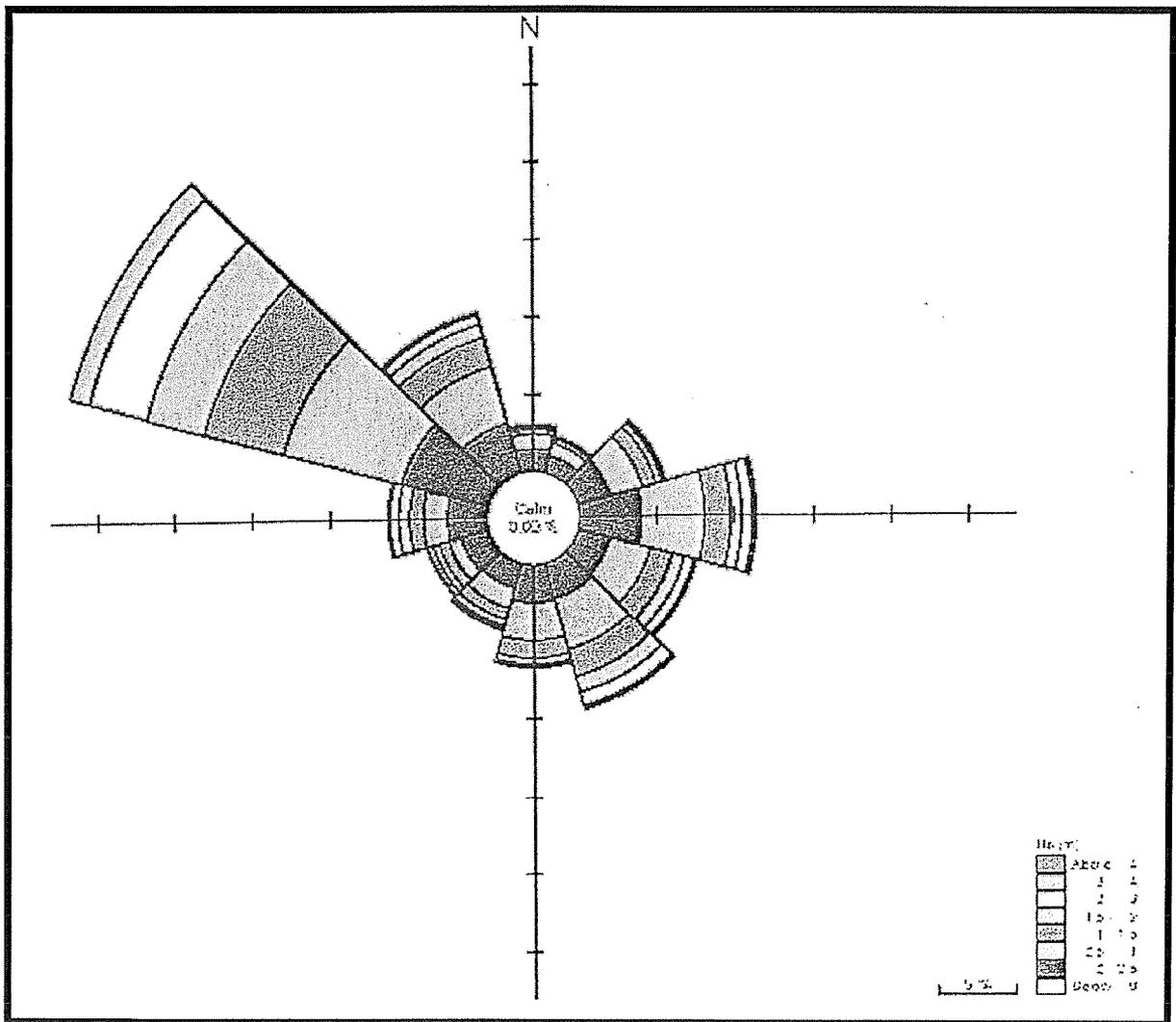




# ***Appendix IV***

# Offshore significant wave height rose

(Taken from 4 points around the Maltese Islands)



Source: UKMO European wave model in MMA, 2003

