14 The Spectacular Landslide-Controlled Landscape of the Northwestern Coast of Malta

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Abstract

The northwestern coast of Malta is characterised by spectacular geomorphological landscapes and by the presence of various types of landslides at different stages of evolution. The generation of landslides has been favoured by the geological situation, which comprises a highly jointed limestone cap rock cropping out above marls and clays. It is because of its aesthetic and natural value, plus its scientific and historic interest, that the northwestern coast of Malta has been included in the UNESCO World Heritage Tentative List and, in addition, a large portion of the coast in this area has been incorporated in the Il-Majjistral Nature and History Park.

Keywords

Landslide • Coastal geomorphology • Cliff • NW Malta

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14.1 Introduction

The northwestern coast of the island of Malta is characterised by a spectacular landscape resulting from the interplay of tectonics, gravity and marine action, which has included Quaternary sea-level change. Its morphology is also under the control of geological features that occur in this part of Malta. At a larger scale, the landforms along this stretch of coast depend on the presence of a horst-and-graben structure, which is responsible for both a series of ridges and valleys generally trending ENE-WSW, and for the location of promontories and bays (Alexander 1988). At a local scale, both the network of tectonic discontinuities (i.e. faults and joints) and the presence of limestones and clay/marls, with differing mechanical properties, control the distribution of landforms which include landslides (Devoto et al. 2013).

A large portion of the area described in this chapter is included within the Il-Majjistral Nature and History Park that was established by the Maltese Government in 2007 (Rolé 2019, Chap. 24). Due to its high landscape value, this area has also been included in the UNESCO World Heritage Tentative List since 1998[1] under the category of 'Coastal Cliffs'. The whole of the northwestern Maltese coast is characterised by spectacular coastal cliffs, which can reach height of 130 m and have been formed in coralline limestones. Along this stretch of coast, a limestone cap rock overlies almost continuous outcrops of Blue Clay. The latter is characterised by low values of friction angle and cohesion and by high smectite content (approximately 40%; Dykes 2002). The poor geotechnical properties of clays and the superimposition of limestones over them have favoured the generation of landslides of different types and sizes, which can be considered as a landmark of the entire area. For both their scientific interest and scenic value, some of these landslides have recently been recognised as geomorphosites (Coratza et al. 2011; Cappadonia et al. 2018).

[1]http://whc.unesco.org/en/tentativelists/979/.

In order to fully understand the complex landscape evolution of the northwestern coast of Malta, it is necessary to trace the evolution of the area to at least the Last Glacial Maximum (LGM) when the Maltese archipelago was connected to Sicily (Italy), so forming a wide peninsula. At that time and until about 20,000 years ago, sea level was around 130 m lower and more land surface was exposed (Fig. 14.1), shaping the geography of the archipelago very differently from what is exhibited today (Furlani et al. 2013). The extensive landslides, which nowadays characterise the northwestern coast of Malta, developed on hillslopes not far from the coast, when the sea level was much lower than today (Soldati et al. 2018). In the Holocene, sea level rise has covered most of the landslide deposits. Recent research has discovered impressive landforms on the Maltese seafloor—including slope-failure deposits—which are crucial for deciphering the complex evolution of the area during the last millennia (Micallef et al. 2013; Foglini et al. 2016).

14.2 Geographical Setting

The northwestern coast of the island of Malta is encompassed between the Marfa Ridge promontory to the north and the Great Fault to the south (Fig. 14.1). This portion of the island is only sparsely urbanised, but is important to the Maltese economy because of its agriculture and tourism. In this coastal zone, ENE–WSW oriented valleys alternate with wide limestone plateaux and ridges, whose altitudes do not exceed 200 m (Fig. 14.1). To the west, sea cliffs or vertical scarps occur, which overlay gentle slopes that are often used for agriculture. Along the coast, limestone cliffs, shore

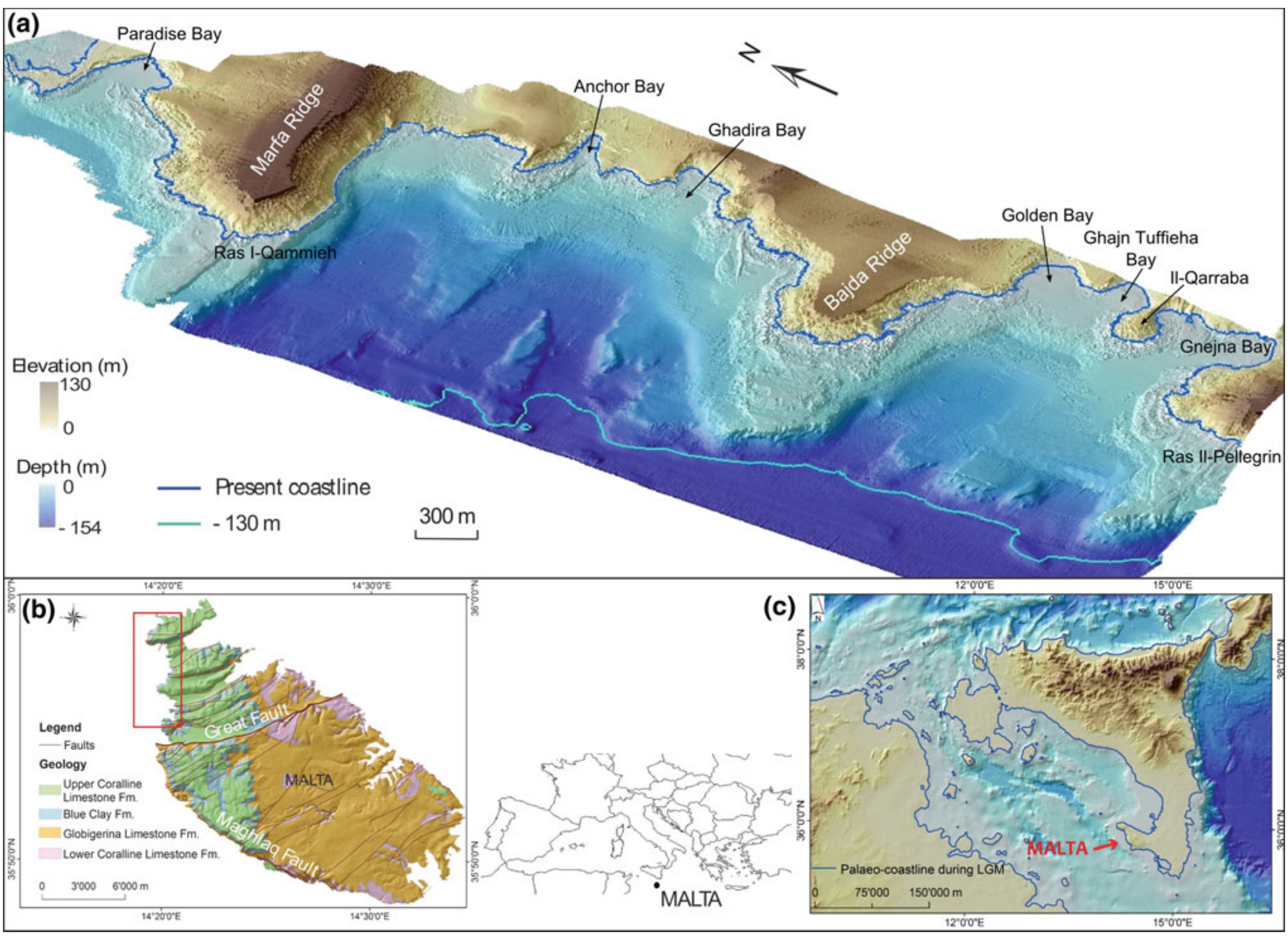

Fig. 14.1 Geographical and geological setting: **a** 3D overview of the NW coast of Malta. **b** Geological sketch of the Island of Malta with indication of area described in the chapter. **c** Palaeogeographic sketch of the Sicily channel during the LGM

platforms and sandy beaches are found, whilst to the south of the Great Fault, limestone cliffs are dominant (Biolchi et al. 2016; Gauci and Scerri 2019, Chap. 5).

The whole area is popular with tourists and local people alike, who make use of its natural trails. The coastal zone also displays important habitats, which are part of the list of Natura 2000 network of the European Habitats Directive[2] (Spiteri and Stevens 2019, Chap. 28). The rural, historical and military heritage of the area is closely related to the landscape. These features include ancient towers, barracks, cart-ruts, long rubble walls (dry stone walls), farmhouses, natural caves and numerous stone huts (Coratza et al. 2011).

The climate of the northwestern coast of Malta is typically Mediterranean, with temperate winters, rainy autumns and long, dry and hot summers (Schembri 2019, Chap. 2). The mean monthly temperature varies from 12 °C in January to 27 °C in August. Rainfall is strongly influenced by the presence of the sea and by the relative flat morphology of the islands, the annual average being slightly in excess of 560 mm (Said and Schembri 2010, Mantovani et al. 2013). Mistral winds, named in Maltese 'Majjistral', blow from the north-west. They collect moisture from the sea, causing rainfall to be slightly higher than for the rest of the island. This wind gives its name to the Il-Majjistral Nature and History Park, which was created to protect the entire coastal stretch between Anchor Bay in the north and Golden Bay in the south (Rolé 2019, Chap. 24).

14.3 Geological and Geomorphological Setting

Except for limited Quaternary deposits, the Maltese archipelago consists of sedimentary rocks spanning from the late Oligocene to the Miocene (Pedley et al. 2002, Baldassini and Di Stefano 2017). This sedimentary sequence comprises a variety of rocks which are primarily limestones and clays (Scerri 2019, Chap. 4). The succession starts and ends up with resistant limestones, respectively the Lower Coralline Limestone and the Upper Coralline Limestone formations. Intermediate units are made up of softer yellowish fine-grained biomicrites belonging to the Globigerina Limestone Formation and overlying clayey and marly terrains of the Blue Clay Formation (Dart et al. 1993; Pedley et al. 2002). Quaternary deposits, mostly Pleistocene in age, are of limited outcrop and take the form of cliff breccias, cave and valley loams, and sands and gravels (Scerri 2019, Chap. 4). Soil is thin but intensively cultivated, especially on terraced hillslopes.

The whole sequence is tilted at 4° to the north-east and is crossed by two fault systems. The older is ENE–WSW-oriented and its major lineament, the Great Fault, lithologically and structurally divides the island into a northern sector, which is deeply controlled by this tectonic trend, and a southern sector (Fig. 14.1; Gauci and Scerri 2019, Chap. 5), where Globigerina Limestone Formation rocks dominate. In the northern sector, the Upper Coralline Limestone (Upper Miocene) and underlying Blue Clay (Middle to Upper Miocene) are dominant lithologies. Outcrops of the Globigerina Limestone (Upper Oligocene to Middle Miocene) and Lower Coralline Limestone (Upper Oligocene) formations along the northwestern coast are limited to the southern coastline of Marfa Ridge and to eastern coastal cliffs of Ġnejna Bay and the Il-Pellegrin promontory.

The ENE–WSW oriented faults generate a horst-and-graben structure which controls the landscape of northern part of the island (Alexander 1988; Gauci and Scerri 2019, Chap. 5). The horsts are characterised by Upper Coralline Limestone plateaus overlying gently sloping surfaces in Blue Clay. Along the coast, they coincide with E-W oriented promontories, such as those of the Marfa Ridge and Bajda Ridge (Gauci and Scerri 2019, Chap. 5). The grabens correspond to inland valleys and to coves and bays along the coast, where sandy beaches are often to be found (Zammit Pace et al. 2019, Chap. 18). The most popular of these beaches are located in Paradise Bay, Golden Bay, Għajn Tuffieħa Bay and Ġnejna Bay.

Mass movements of varying types and sizes are widespread along the northwestern coast of Malta. They range from rock falls affecting the limestone cliffs, to earth flows and slides in the softer clays and marly terrains. The most spectacular gravity-induced features are the extensive block slides, which typify the whole area.

Block slides are typical of the so-called rdum landscape (i.e. limestone boulders scattered over Blue Clay). Within the cliff system, there is also evidence of karst processes that affect the limestone plateau which favour water infiltration and the formation of perched aquifers supported by the impermeable Blue Clay aquiclude. Narrow gorges and dry valleys—locally known in Maltese as 'widien'—interrupt the cliffs and terraced areas, which have long been used for agriculture, occur within the Blue Clay slopes at the foot of the limestone cliffs.

14.4 Coastal Landslides: Controls and Distribution

A series of landslide-controlled landforms can be recognised along the northwestern coast of Malta, from Marfa Ridge to Ras Il-Pellegrin (Sammut 2019, Chap. 16). The majority of

[2] http://mt.majjistral.org/home.

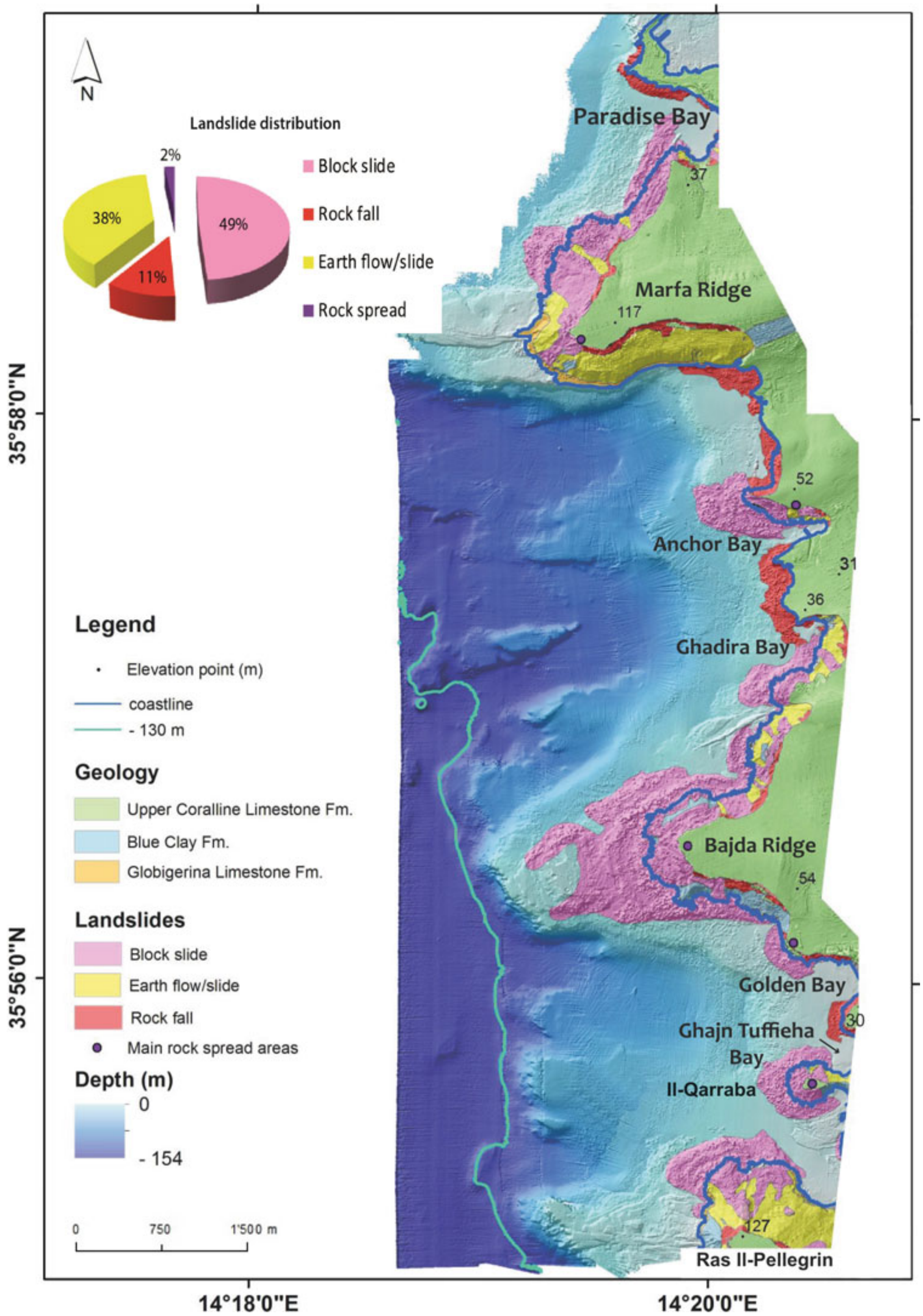

Fig. 14.2 Onshore and offshore landslide distribution along the NW coast of Malta

coastal slope failures consist of extensive slow movements affecting the Blue Clay and the overlying Upper Coralline Limestone. The most widespread are rock spreads and block slides, which make up the 51% of the areas affected by mass movements along the coast (Fig. 14.2). Evidence of rock fall deposits at the foot of the limestone cliffs and earth flows/slides within the Blue Clay is, however, clear at some locations (Magri et al. 2008; Devoto et al. 2012, 2013).

The main factor causing the extensive rock spreads found along the northwestern coast is the difference in geo-mechanical and geotechnical properties between the brittle Upper Coralline Limestone and the ductile Blue Clay terrains (Mantovani et al. 2013). Lateral extension occurs at the edges of the karst plateaus and produces high loads that cause the underlying clays to behave visco-plastically, especially when wet (Pasuto and Soldati 2013). Lateral

Fig. 14.3 Tilted blocks detached from the Upper Coralline Limestone cliff edge in the northern sector of Marfa Ridge. The blocks have reached the sea sliding over the Blue Clay terrains, making up a natural protection towards wave action

spreading of the limestone cap rocks, favoured by the presence of joints, produces trenches and fissures which may easily be recognised along the edges of the plateaus. The Blue Clay locally shows swelling and bulging due to this deformation and rock spreading evolves into block-sliding, as witnessed by the numerous huge blocks that are detached and displaced from the limestone plateaus and often reach the sea. Rock blocks may be tilted at high angles due to the deformation and/or sliding which occurs within the Blue Clay. Along the coast, the accumulation of displaced rock blocks tend to protect coastal slopes from wave action, preventing erosion and/or undercutting, as is clearly observable at Marfa Ridge (Fig. 14.3)—between Għadira Bay and Bajda Ridge—and at Il-Qarraba. The style and morphological features of block slides appear to be connected to the orientation and density of joints and to the thickness of the limestone cap rock in comparison with that of the underlying clayey materials. The largest block slide deposits occur where the limestone plateaus have thickness of at least 10 m and Blue Clay outcrops at sea level with a thickness varying between 20 and 50 m. These geological conditions are observable in the northern sector of Marfa Ridge and along the stretch of coast comprised between Rdum id-Delli and Bajda Ridge. The thicknesses of the limestone cap and the Blue Clay formation vary along the coast due to the ancient marine sedimentary conditions at the time of their formation.

Block slide deposits extend hundreds of metres below sea level reaching a depth of ca. 40 m (Prampolini et al. 2019, Chap. 10). Using a multibeam survey, the seafloor morphology of northwestern coast of Malta was reconstructed for a distance of 1.6 km from the shore and over a length of 7.5 km from Marfa Ridge to Ras Il-Pellegrin (Foglini et al. 2016; Prampolini et al. 2017, 2019, Chap. 10). Extensive 'hidden' accumulations of blocks were recognised and interpreted as the submerged portions of block slides which may be observed onshore. The latter often appear to be only a part—around one-third—of the entire landslide bodies. According to recent cosmogenic ray exposure dating, the onset of these huge landslides were already active during the LGM when the sea level was much lower than today (Soldati et al. 2018). The most ancient dated detachments occurred

21.7 ± 1.4 kyr ago at Anchor Bay and 15.3 ± 1.0 kyr ago at Il-Qarraba, when the sea level was, respectively, 130 and 115 m lower (Prampolini et al. 2019, Chap. 10). The more humid climate conditions at the time probably favoured landsliding due to a higher infiltration of water, moistening the Blue Clays. More recent detachments occurred when the sea level started interacting with block slides. The most spectacular landslide-controlled landscapes and landforms of the northwestern coast will be described below from north to south.

14.4.1 Marfa Ridge

The southwestern edge of the Marfa Ridge, from Paradise Bay to Ras Il-Qammieħ (Fig. 14.4), is affected by landslide processes which produce distinctive landforms. The whole promontory shows spectacular examples of lateral spreads and block slides at different stages of evolution, accompanied by rock falls and topples at the base of the cliffs. The Upper Coralline Limestone plateau, which caps the clayey slopes, is intensely cracked (Fig. 14.4b). This has favoured the progressive detachment of large blocks from the cliff edges (Fig. 14.4c) which have then moved over the Blue Clay because of its deformation mainly caused by rainwater infiltration. The blocks show different degrees of tilting, representing both varying stages of evolution and local controls (in particular the different ratio between Upper Coralline Limestone and Blue Clay thickness). Landslide accumulations extend below the sea level and scattered limestone blocks may be found up to 260 m from the coastline (Figs. 14.2 and 14.4a).

On the southern side of the promontory, Globigerina Limestone crops out at sea level, limiting the extension of landslides which are mainly restricted to earth flows that affect the Blue Clay slopes. The latter are characterised by

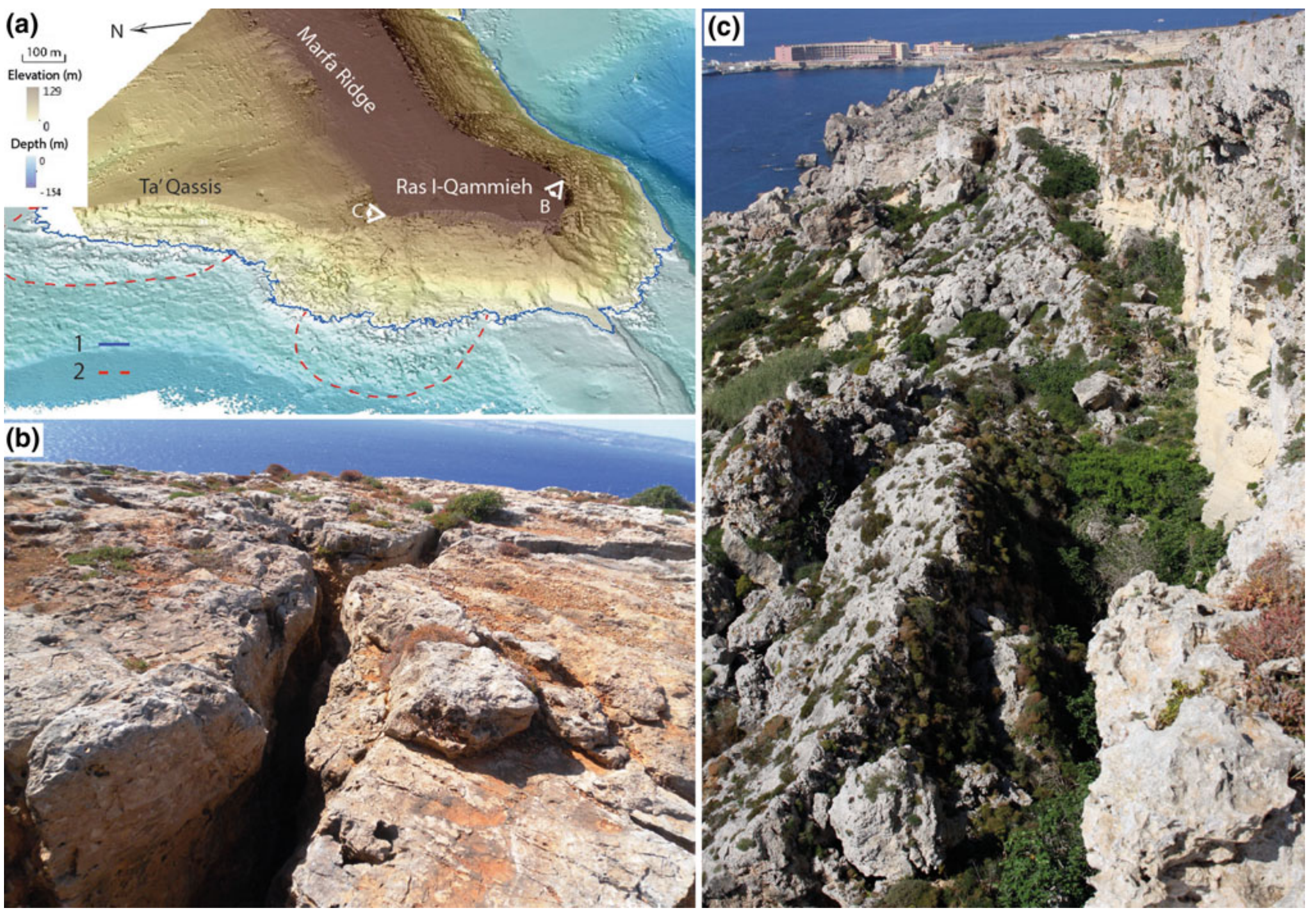

Fig. 14.4 Rock spreading and block sliding at Marfa Ridge: **a** DTM of Marfa Ridge and surrounding seafloor, including photograph views; legend: (1) present coastline; (2) boundary of the submarine landslide deposit. **b** Major fissure affecting the Upper Coralline Limestone plateau. **c** Large block slide deposit affecting the NW side of Marfa Ridge

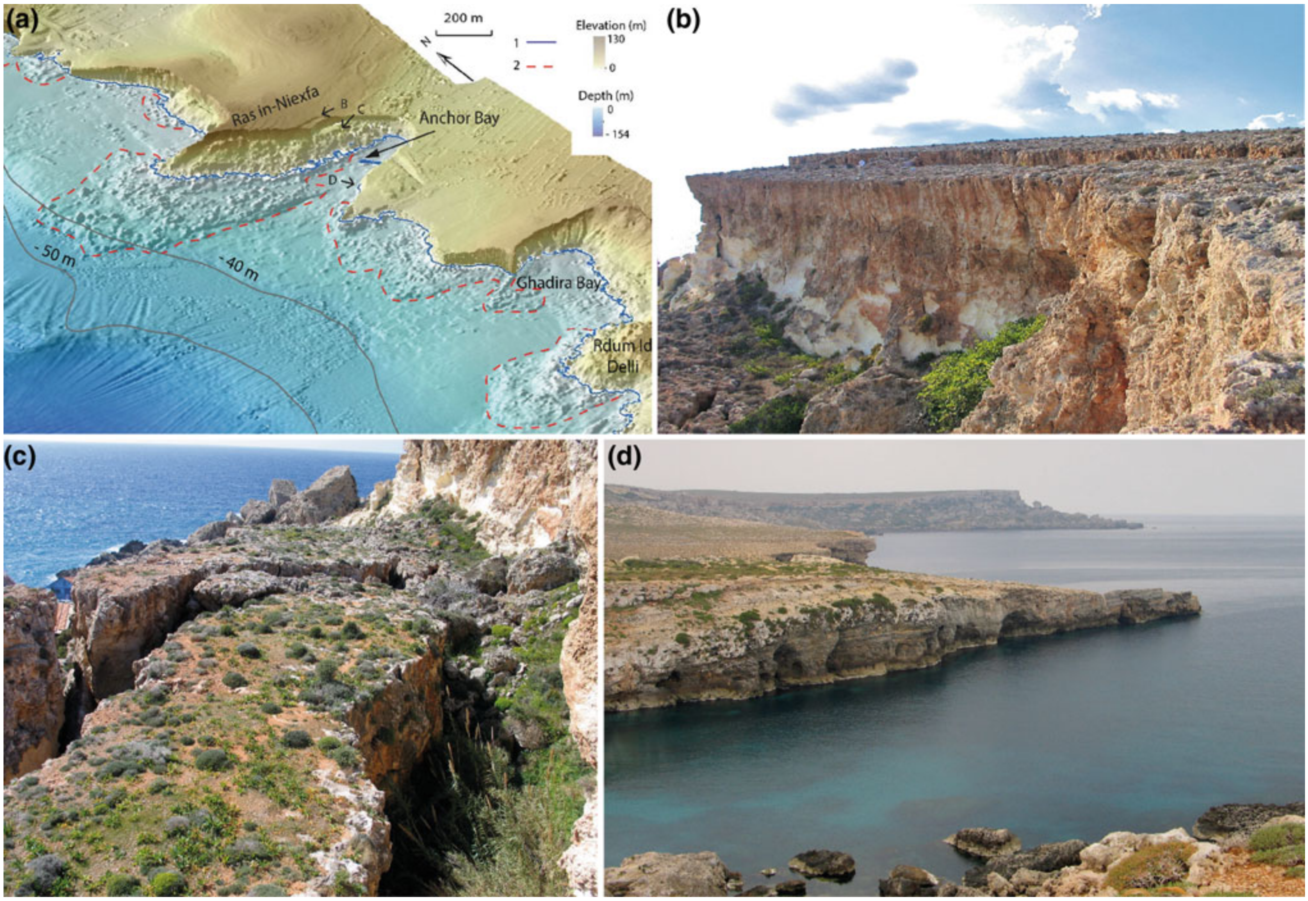

Fig. 14.5 Rock spreading and block sliding at Anchor Bay: **a** DTM of Anchor Bay area and surrounding seafloor; legend: (1) present coastline; (2) boundary of the submarine landslide deposit; location of the areas depicted in photographs b, c, and d are reported. **b** South-facing side of Ras in-Niexfa promontory affected by rock spreading causing a vertical displacement up to 2 m (upper scarp) and block sliding responsible for the main scarp reaching 20 m (lower scarp). **c** Cracked block slide unit at the foot of the main scarp. **d** Southern side of Anchor Bay characterised by an Upper Coralline Limestone cliff

terraces that have been built for agriculture. On the sea floor no evidence of landslide deposits has been found.

14.4.2 Anchor Bay Area

The elongated shape of Anchor Bay (Il-Prajjet) is related to the presence of E-W oriented faults. On the north side of the bay, the superimposition of Upper Coralline Limestones over the Blue Clay has favoured lateral spreading, which has evolved into an impressive block slide affecting the whole northeastern part of the inlet (Fig. 14.5a). The limestone blocks detached from the plateau are lowered, tilted and extend for about 300 m across the sea floor mainly to the west. They comprise a large accumulation that reaches a depth of more than 40 m (Mantovani et al. 2013).

Slope movement affects the inner part of the south-facing side of the Ras in-Niexfa promontory. Here the edge of the plateau is affected by rock spreading that produces persistent cracks and fissures, which vertically displace the limestone cap by up to 2 m (Fig. 14.5b). Below, an impressive scarp, up to 20 m high, separates the plateau from a remarkably displaced and cracked unit oriented approximately parallel to the coast (Fig. 14.5c).

The rugged morphology of the north side of the bay was found suitable for locating the set of the Disney film Popeye (starred by Robin Williams and directed by Robert Altman) in 1980. The set of the film is presently used as an amusement park, which attracts a high number of visitors each year.

The morphology of the southern side of Anchor Bay is completely different due to the presence of an E-W oriented fault that almost cuts across the inlet in the middle. As a result, the southern side of the bay is made up by a vertical cliff up to 25 m in height which is entirely made up of Upper Coralline Limestone (Fig. 14.5d). Here the Blue Clay crops out below sea level. The cliff has been affected by rock falls and is characterised by the presence of three marine caves.

14.4.3 Bajda Ridge Promontory

Other outstanding examples of rock spreads and block slides are located between Għadira Bay and the western promontory of the Bajda Ridge (Fig. 14.6a). Here notable block slide features occur, especially between Rdum id-Delli and Ras il-Waħx (Fig. 14.6c). Along this section of coast, block slides alternate with earth flows and slides, which are also common, especially at Għadira Bay (Fig. 14.6b). The latter are often faster and may be triggered or re-activated by intense rainfall. Locally, these earth flows and slides are able to displace limestone blocks that are detached from cliffs cut into Upper Coralline Limestone.

The landslides affecting this stretch of the coast show a remarkable offshore runout; this being especially the case of the Bajda Ridge block slide (Fig. 14.6a, d). This is the most outstanding and extensive block accumulation described in this chapter. It extends for about 700 m from the coastline and reaches a depth of 40 m. The landslide deposit on the seafloor is mostly W-E-oriented and follows the trend of the ENE–WSW fault system, which controls the morphology of the Bajda Ridge (i.e. it is a tectonic horst structure).

14.4.4 From Għajn Tuffieħa Bay to Ġnejna Bay

From a landscape perspective, Għajn Tuffieħa Bay is probably the most spectacular location on the western coast and is appreciated by tourists and local people for its outstanding

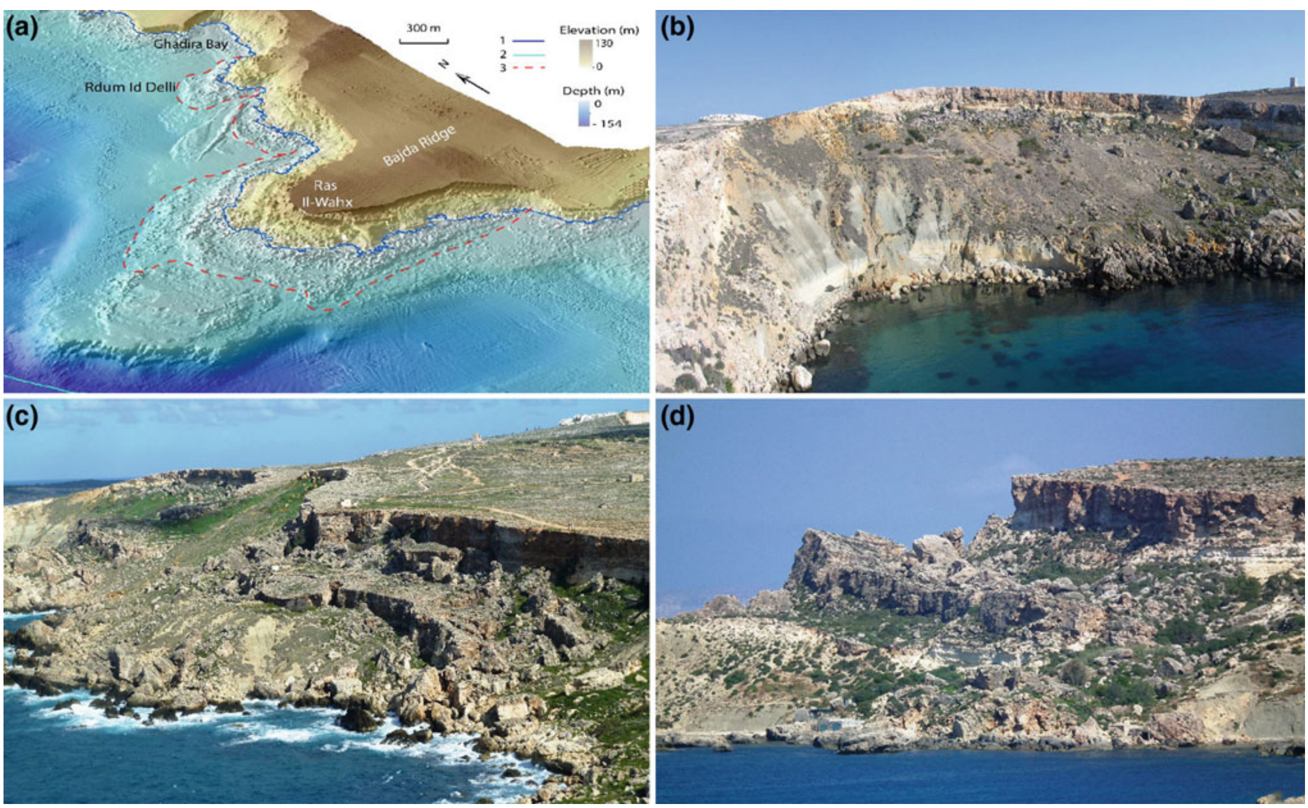

Fig. 14.6 Coastal landslides between Għadira Bay and Bajda Ridge: **a** DTM of Bajda Ridge area and surrounding seafloor; legend: (1) present coastline; (2)—130 m contour line; (3) boundary of the submarine landslide deposit. **b** Clayey coastal slope at Ghadira Bay affected by earth flows/slides and gully erosion. **c** Rock spreading and block sliding between Rdum Id-Delli and Bajda Ridge. **d** Southern side of Bajda Ridge promontory

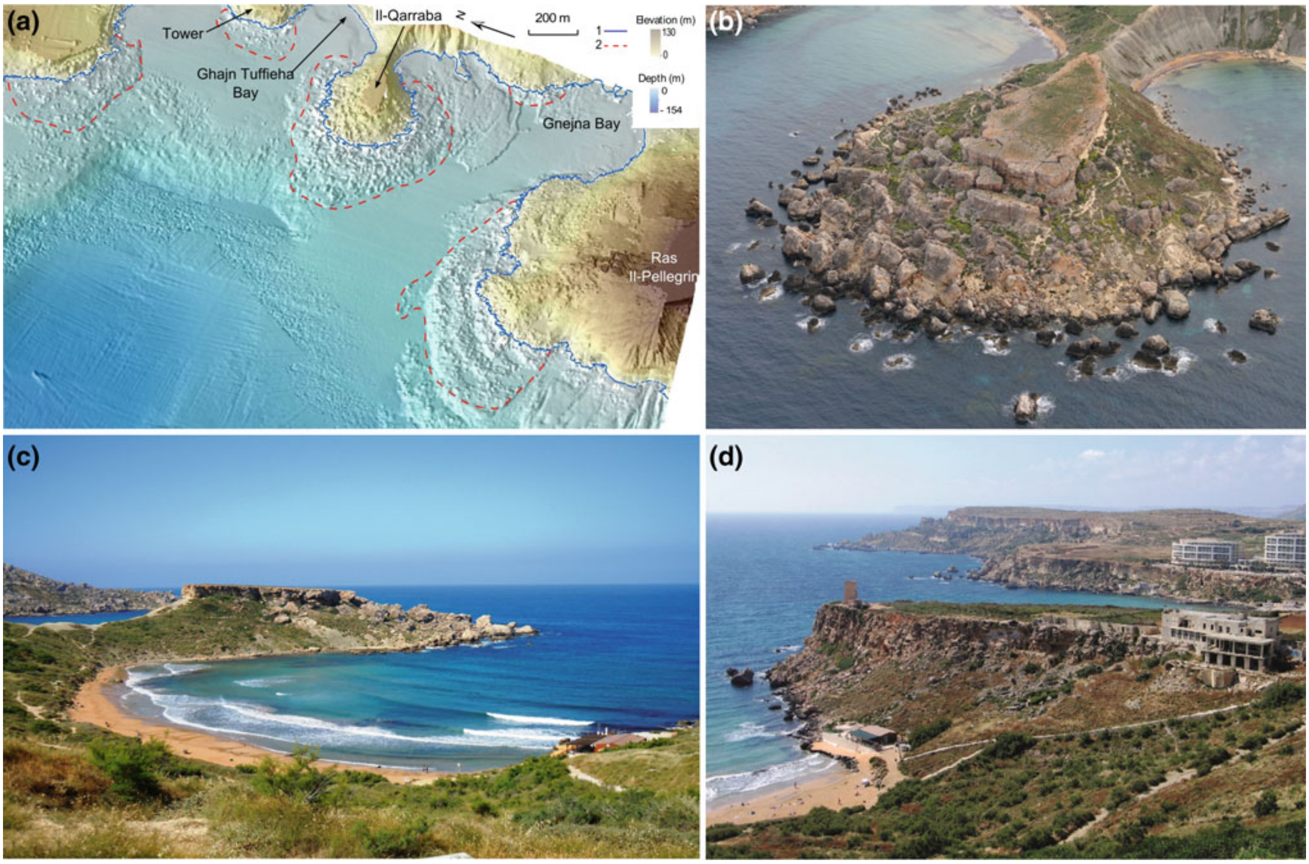

Fig. 14.7 Coastal landforms between Għajn Tuffieħa Bay and Ras Il-Pellegrin promontory: **a** DTM of the area and surrounding seafloor; legend: (1) present coastline; (2) boundary of the submarine landslide deposit. **b** Aerial view of Il-Qarraba plateau affected by spectacular block slides. **c** Għajn Tuffieħa Bay and, in the background, Il-Qarraba peninsula. **d** Għajn Tuffieħa northern side with the historical defence tower and the ruins of a hotel affected by landslides

scenery. This wide bay is limited to the north by a rocky promontory and to the south by the head-shape peninsula of Il-Qarraba, which separates the bays of Għajn Tuffieħa and Ġnejna (Fig. 14.7).

The rock formations cropping out in the area are, from top to bottom: the Upper Coralline Limestone; Blue Clay and Globigerina Limestone. This succession of three rock types is not observable everywhere due to the presence of a series of nearly vertical faults, which have displaced bedrock in some locations. The western part of the promontory in the vicinity of Għajn Tuffieħa Bay consists of the Upper Coralline Limestone forming a cliff about 27 m in height which plunges into the sea. A coastal defence tower built in 1637 dominates the northern part of the bay (Fig. 14.7d). The tower is located at the edge of a cliff which is retreating due to rock falls and is, thus, at risk of being damaged. Towards the inner part of the bay the Blue Clay begins to crop out below the Upper Coralline Limestone cap. Due to slope instability of the Blue Clay, a hotel whose ruins are still visible was irreparably damaged in the late 1970s during an episode of intense rainfall (Fig. 14.7d). Where the Blue Clay is present along the inner part of the bay, slopes descend more gently from the base of the plateau to the coastline. The bay consists of a sandy beach stretching over a distance of almost 300 m and is backed by Blue Clay slopes reaching an altitude of about 60 m asl (Fig. 14.7c). Here a recent re-vegetation scheme has made the clayey slopes more stable, though locally earth flows and slides are still visible. Some of them are able to carry limestone blocks and debris down to the beach (Dykes 2002).

The central part of the Il-Qarraba peninsula is capped by a flattened Upper Coralline Limestone slab (Fig. 14.7b), whose altitude reaches 42 m and which offers panoramic views of the Il-Pellegrin Promontory, Golden Bay and Għajn Tuffieħa Bay. The presence of limestone above clayey and marly terrains has favoured spectacular rock spreading and blocks sliding, as witnessed by the occurrence of large blocks that are detached from the plateau above and which reach the coastline so armouring the head of the promontory against wave action. This block-slide accumulation extends below the sea level for about 200 m and reaches a depth of 25 m (Fig. 14.7a). This wide submarine deposit clearly witnesses the progressive

Fig. 14.8 Southern side of Il-Qarraba peninsula; gully erosion on the Blue Clay is clearly visible

disruption of the Il-Qarraba plateau that caused a remarkable reduction of its size on a long span of time.

A thin isthmus made up of Blue Clay connects Il-Qarraba to the mainland (Fig. 14.8). The absence of a limestone cap has favoured erosion processes and these are clearly still active today.

South of Il-Qarraba promontory, steep and bare Blue Clay slopes occur. Here the action of surface water has incised deep rills and gullies making up a landscape of spectacular badlands (Fig. 14.9). The steepness of the Blue Clay slope is favoured by wave action, which also causes toe erosion. Around 200 m south of Il-Qarraba, sea action is less intense due to cropping out at sea level of the more resistant Globigerina Limestone which continues to Ġnejna Bay. Ġnejna Bay is characterised by the presence of two wide shore platforms, a pocket beach and rocky cliffs, whilst to the south local people have excavated small caves in the rock to store boats. Ġnejna Bay terminates at Ras il-Pellegrin promontory, which reaches a height of almost 130 m.

14.5 Conclusion

The northwestern sector of the island of Malta may be considered a geological laboratory for the study of coastal landslides and their influence on long-term geomorphological evolution. The distinct geological conditions, especially the superimposition of rock types showing differing mechanical behaviours and intense jointing of the rock masses, has favoured the development of exemplary cases of landslides of different types. In view of the fact that the stratigraphic sequence is relatively simple and vegetation cover is scarce, the area is ideal for a successful application of several methods and techniques of research, from the most traditional (geomorphological survey and mapping, aerial photo-interpretation, landslide monitoring) to the most innovative (Persistent Scatterer Interferometry and multi-beam surveys). Recent and ongoing research is aimed at monitoring active landslides and defining hazard conditions (Mantovani et al. 2013; Piacentini et al. 2015; Mantovani

Fig. 14.9 Gully erosion on the Blue Clay slopes south of Il-Qarraba. On the right hand-side, the contact between the Blue Clay (below) and the Globigerina Limestone (the top surface) is evident

et al. 2016). Long-term GNNS monitoring and satellite interferometric analysis showed remarkable geomorphological dynamics including coastal cliff instability and widespread active block sliding (Magri et al. 2008; Mantovani et al. 2013; Piacentini et al. 2015; Mantovani et al. 2016). On the other hand, investigations were carried out to reconstruct long-term landscape evolution of the area based on an integration of terrestrial and marine geological and morphological data sets (Foglini et al. 2016; Prampolini et al. 2017; Soldati et al. 2018).

Recent research has also taken into account the remarkable geoheritage of the area (Coratza et al. 2011) outlining and assessing the geosites present in this part of Malta. This is a crucial aspect to be exploited, especially inside Il-Majjistral Nature and History Park where visitors can have a holistic approach to the natural landscape (including the rich biological component), and to the historical and architectonic assets which characterise the area, possibly being aware of hazardous conditions (May 2008).

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