Rocks

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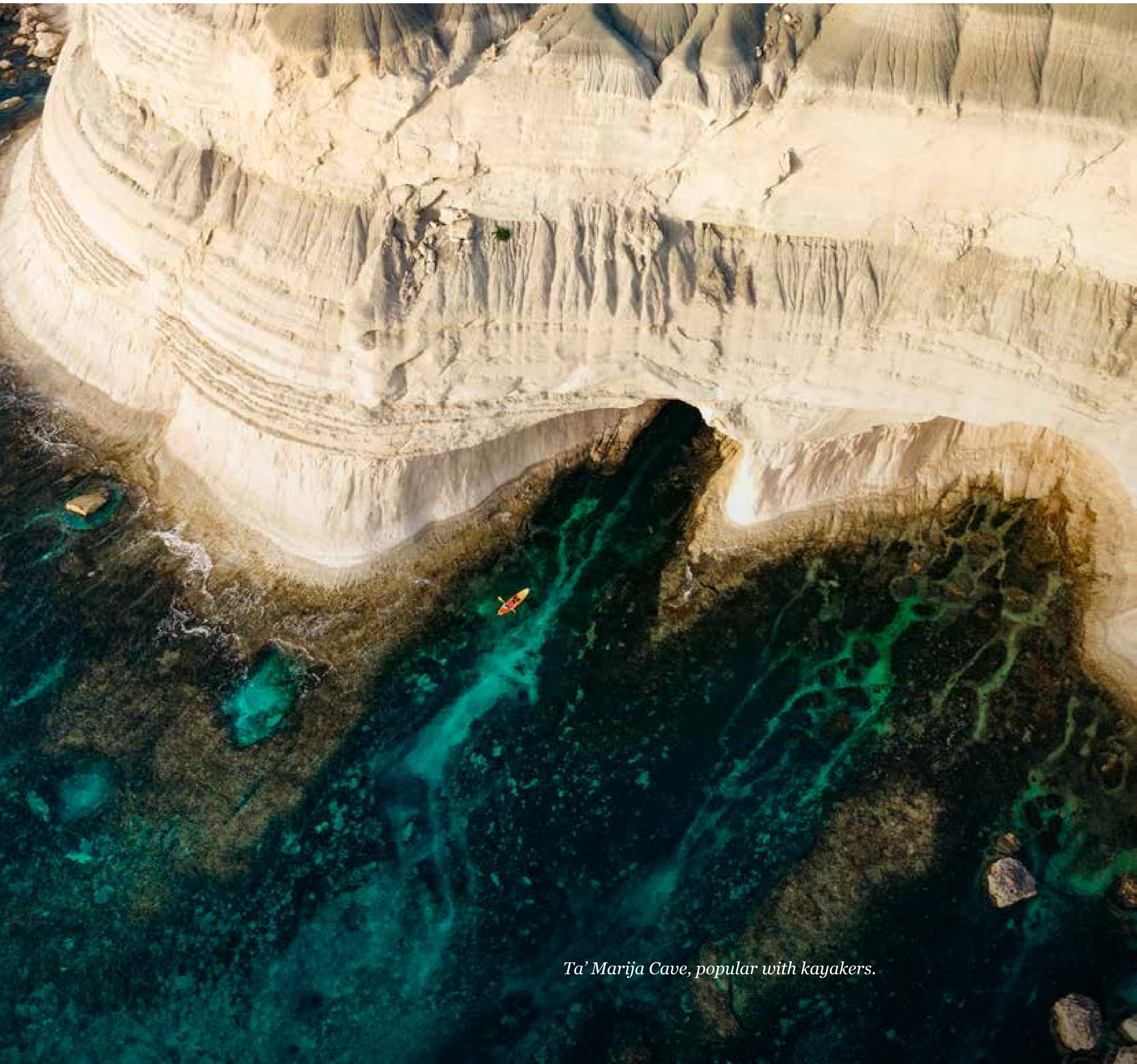


Ta' Marija Cave, popular with kayakers.

Rocks: Envoys of natural transformation

Though we often think of rocks as static and immutable, every single geological record along the Maltese coast tells a story of dynamic transformation. Rocks are far from inert; they are the visible manifestation of millions of years of natural forces: marine sedimentation, tectonic upheavals, impactful waves, relentless winds, and the slow imperceptible work of weathering. The rocky coasts of the Maltese Islands are a testament to this continuous evolution, capturing the eternal struggle between rock resistance, erosion and deposition. To walk along the Maltese limestone shores is to witness geology as a living record, where each cliff face, boulder, pebble or sand grain reflects the intricate geological and geomorphological processes that sculpted the Islands' distinctive coastline.

Coasting the Maltese geology: Five main formations

Despite its modest size, the Maltese coastline boasts a geological diversity that is characterised by a marine-derived sequence of five main sedimentary formations, dating back to the Oligocene and Miocene epoch i.e., around 28 to 7.5 million years ago. These rock units are a mix of limestone, marls, and clays, and represent the islands' complex history of environmental changes in central Mediterranean. Marine deposits were injected with calcium carbonate-rich shells and built into a multi-layered platform that subsequently emerged above sea level by tectonic uplifting forces around 5 to 7 million years ago. When this sedimentary base emerged above sea level, terrestrial deposits of Quaternary age (from 2.5 million years ago) began to accumulate in pockets across the landscape, rapidly infilling caves with fossiliferous deposits, washing out fluvial deposits on the coast as clastic-rich fans or depositing fine debris as aeolian (wind-derived) deposits into dunes.

The marine sedimentary structure is primarily composed (from the oldest to youngest) of five rock strata: Lower Coralline Limestone (LCL), Globigerina Limestone (GL), Blue Clay (BC), Greensand (GS), and Upper Coralline Limestone (UCL). Three of these limestone strata are further subdivided into members based on distinct physical and chemical traits, such as sea-bed fossil content, grain size, colour, and hardness. These characteristics reflect environmental shifts at the time of deposition, including variations in sea level, climate, and biological activity. These five stratigraphic layers have in turn significantly influenced the coastal geomorphology of the Maltese Islands.

The Lower Coralline Limestone (MT: Żonqor or Qawwi ta' Isfel) is the oldest rock formation visible in the Maltese archipelago, dating back to the Oligocene epoch, around 28 million years ago. It constitutes 36% of the Maltese coastal geology. This massive limestone is composed predominantly of bioclastic calcarenite (made from broken shells and other marine life remains) and is characterized by a dense, light grey to brownish hue. Its resistance to erosion makes it the backbone of Malta's most dramatic coastal features, such as the towering sea cliffs along the southwestern coastlines of Malta and Gozo, including Ta' Ċenċ cliffs, which rise 140 metres above sea level. LCL also appears prominently along fault lines on the north-eastern and southern coasts, such as from Madliena Tower to the Dragut Point (Sliema), and along Marsaskala Bay. Tectonics would have played a role in tilting and fracturing the exposed limestone, creating rectilinear fault-derived cliffs and causing sections of the LCL to be exposed at or near the surface on these coasts. Sub-divided into four members (Magħlaq, Attard, Xlendi and Mara), LCL is rich in fossilized remains of ancient marine organisms like coralline algae, bivalves, and echinoids, which reflects a range of marine depositional environments, from shallow lagoons to deeper channels.

Lying atop LCL, is the more erodible Globigerina Limestone (MT: Franka or Soll), which is the most extensively exposed rock formations, spanning the late Oligocene to middle Miocene epochs (23-13 million years ago). Known for its characteristic pale yellow to cream hue, this softer limestone is composed primarily of biomicrites (i.e., fragments of shells or corals embedded in fine-grained sediment) and are rich in Globigerina foraminifera: these are microscopic marine organisms which flourished in the ancient warm seas that once covered the region. With thicknesses varying significantly from 20 metres in some coastal areas to over 200 metres in central Malta, the GL has played a central role in shaping the island's undulating coastal landscapes. It accounts for 35% of the Maltese coastal geology.

Divided into three main members - Lower, Middle, and Upper Globigerina Limestone - each layer reflects subtle differences in composition and depositional environment, largely due to fluctuations in ancient sea levels and sedimentation rates. The Lower (LGL) and Middle (MGL) members are separated by a distinct phosphatic conglomerate, while a similar phosphatic layer divides the Middle and Upper (UGL) members. These layers mark interruptions in sedimentation, likely tied to changes in sea levels or shifts in marine currents. When exposed at sea level, these conglomerate beds are resistant to wave erosion and hence favour the development of shore platforms such as in Sliema, Xwejni (Gozo) and Marsaskala.

MGL is typically finer and less compact, which leads to steeply inclined coastal cliffs where it is exposed, such as along St. Thomas Bay and west of the Delimara Peninsula. Its marl-rich beds, containing fragments rich in phosphate and glauconite minerals, are prone to erosion and mass movement, as seen in areas like Xrobb l-Għaġin. LGL also forms low coastal cliffs that frequently fracture due to the presence of fissures and joints, which are widened and undercut by wave action. These low cliffs are visible along various north-eastern coasts of Malta, including Selmun, St. Paul's Bay, Sliema, Xgħajra, and Marsaskala. Notably, there is growing concern about the rapid deterioration of coastal fortifications, such as at Fort Ricasoli, limits of Kalkara, due to the undercutting of LGL.

The Blue Clay (MT: Tafal) formation dates back to the middle Miocene (13 to 12 million years ago) and is known for its distinct bluish-grey hue and marl-rich composition. Covering around 9% of the Maltese coastal shores, this clay formation typically ranges from 20 to 75 metres in thickness and is composed of alternating layers of dark-grey and pale-grey marls. The BC is relatively impermeable and restricts water infiltration by directing rainwater as surface runoff, making it particularly susceptible to gully erosion and mass movement. As a result, it forms unstable coastal slopes and is prone to landslides, especially along the north-west part of Malta, such as Għajn Tuffieħa Bay and Ġnejna Bay, where marine erosion accelerates the undercutting process and boulder fields develop below the UCL plateaus.

The Greensand (MT: Rina) formation on the coast is mostly found at elevated heights above the Blue Clay and below the UCL and does not dominate the coastal geology of the archipelago. Though relatively thin, GS is a distinctive layer that adds a bright orange to the island's geological palette. This colour comes from glauconite, a greenish mineral rich in iron and potassium, which turns into orange when oxidised. It typically appears as a friable, granular limestone and ranges in thickness from as little as 0.5 metres on Malta to up to 11 metres in the inland area of Gelmus, Gozo, where it is best developed and more prominently exposed. Due to its limited thickness and tendency to be obscured by talus (a pile of loose broken rocks or debris) from the overlying UCL, the Greensand is often visible only in scattered outcrops. It is visible in around 3% of the Maltese coastal shores.

The fifth and final layer is the Upper Coralline Limestone (UCL). This is the youngest rock formation in the Maltese stratigraphic sequence, dating back to the late Miocene (12 to 7.5 million years ago). This formation is present on 16.6% of the Maltese coast and is composed primarily of hard, massive limestone in cream to pale yellow colour. It is rich in fossilized coralline algae, which indicates a shallow, high-energy marine environment during deposition. The UCL is notably thick, ranging from 10 to 170 metres, and forms the highest points on Malta and Gozo. As part of the elevated topography in the northwest of Malta, the UCL forms high plateaus and rugged cliffs and often does not reach sea level. Instead, it is the underlying layers, such as the Blue Clay and Globigerina Limestone, that are exposed to the sea and its actions. This configuration creates a striking landscape, such as at Qammieħ Point on Marfa Ridge or the north-west coast of Majjistral Park, where the UCL caps the highest elevations, while the underlying, more erodible strata shape the coastline by undercutting and fracturing UCL to develop scree slopes, boulder fields and shore platforms at sea level.

The Quaternary deposits along the Maltese coasts are diverse and reflect environmental shifts and geological processes from the Pleistocene to the present day. These deposits, often fragmentary and predominantly of continental origin, appear in locations where erosion has exposed them or where they have accumulated in valley floors and low-lying areas. They unconformably overlie older marine strata from the Oligo-Miocene age and are easily recognized by their reddish or brownish hues, which are the result of weathering and iron oxide accumulation over time.

Some come in the form of raised beach deposits, such as at Ċirkewwa and Ta' L-Imgħarrqa (Għadira Bay), and are composed of lithified calcareous sands with cross-laminations. These deposits mark ancient shorelines and provide evidence of past sea levels during periods of marine transgression and regression. Others, such at the coast of Għar Lapsi, are fluvial conglomerates and reflect ancient river systems that deposited coarse, terrigenous sediments during the Quaternary period. They not only tell a story of environmental shifts, from wetter climates to today's semi-arid conditions, but also hold clues about past sea levels, animal migrations, and climatic fluctuations that shaped Malta's geological and ecological heritage.

The cliffs at Dwejra (Gozo) close to where the Azure Window once stood.

On the edge of Mediterranean tectonics

The coastal landscape owes much to tectonic movements that faulted and tilted these formations. The islands' position on the Pelagian Block (a carbonate platform in the central Mediterranean Sea) has subjected them to tectonic forces that formed a series of faults which altered the structure of the islands and created a set of distinct structural regions. The ENE-WSW fault-oriented system, primarily represented by the Great Fault has influenced the northern part of Malta. It produced an alternation of horsts (uplifted blocks), and grabens (down-dropped blocks), which created headlands and bays (or rias) respectively along the coast.

To the north, parallel fault systems established a sequence of hills and low-lying basins, most visible as Wardija Ridge, Bajda Ridge, Mellieħa Ridge and Marfa Ridge and which are intersected respectively with bays ending from Binġemma Valley, Pwales Valley, Miżieb Valley and Mellieħa Valley. This faulted landscape allows visitors to experience a range of coastal features, from towering cliffs to secluded creeks and bays.

Additionally, intersecting faults from the NW-SE Pantelleria Rift, developed during the late Miocene and early Pliocene, are evident south of the Great Fault, notably the Magħlaq Fault. In trending parallel to the coastline, this NW-SE fault system significantly impacted the coastline of southwest Malta, particularly near Għar Lapsi and along the coastal cliffs of Dingli. It has created a prominent escarpment with a vertical displacement exceeding 200 metres and contributed to the steep cliffs of the region.

The faulting has led to the exposure of the Lower Coralline Limestone along the coast, forming vertical cliff faces that plunge directly into the sea. This has also resulted in a rugged, fractured landscape where erosion processes are intensified due to the structural weakness introduced by the fault line.

The fault systems have also contributed to a northeast tilt across the Maltese Islands, significantly influencing the landscape's geomorphology. This tilt elevated the western, southwestern, and southern coasts of Malta, exposing the Lower Coralline Limestone in steep or vertical cliffs that create dramatic seascapes. Meanwhile, the eastern and south-eastern coasts feature gently sloping shores. Gozo is also inclined to the NE. Its southern and western coast is characterized by cliffs reaching heights over 120 metres. Where valleys reach the coast, this tilt formed drowned valleys, or ria coastlines, marked by narrow creeks carved into the Globigerina Limestone and Lower Coralline Limestone. No wonder then that Malta's coastal towns and ports all lie on its eastern shores.

Rocks as blueprints: Nine coastal landforms

Thanks to its geology and geomorphology, the Maltese coast presents an impressive variety of landforms that represent the tension of forces at the edge between land and sea. In fact, among the Maltese Islands' most distinctive and picturesque landscapes, many are coastal in nature and can be categorized into nine types of coastal geomorphological landforms:

1. <u>Rias or drowned valleys</u>: During the late Pleistocene (around 20,000 years ago), sea levels were about 120 metres below today's levels. This period saw the formation of a river system extending four kilometres into the continental shelf. As sea levels rose with glacial melting, valleys along the shelf became submerged, resulting in ria coastlines, or drowned valleys, that now serve as natural harbours. Examples include the Grand and Marsamxett Harbours, Marsaskala, Marsaxlokk

Bay, and Wied Babu in Żurrieq. Gozo features similar landscapes at Mġarr ix-Xini, Xlendi, and Wied il-Għasri. In certain areas, these drowned valleys provided conditions conducive to saline marshlands, characterized by sheltered waters and abundant fine sediment deposits. These unique habitats, such as Għadira in Mellieħa Bay and il-Magħluq in Marsaskala, support distinct endemic ecosystems.

2. Low-rocky coasts: Gently sloping rocky shores, featuring pools and pinnacles, are prominent along the north-eastern shores of Malta and northern Gozo. Intense chemical and biological weathering of the LCL creates a rugged, irregular topography, as seen at Baħar iċ-Ċagħaq (Malta). Additionally, fractured LGL coasts offer ideal conditions for large boulders to become dislodged during storms, forming coastal boulder fields. Such boulder-strewn coasts can be found along Malta's north-eastern areas, including L-Aħrax tal-Mellieħa, Buġibba, Qawra, Pembroke, Xgħajra and Żonqor (Marsaskala).

3. Beaches (sandy, shingle, and boulder-strewn): Depositional beaches account for just 2.4% of Malta's coastline. Sandy beaches are more common than shingle beaches, making up 2.2% and 0.2% of the coast, respectively. These beaches are located mainly in sheltered bays bordered by rocky coastlines, where longshore marine currents deposit enough material to form sandy or shingle beaches. In northeast Malta, submerged graben features create shallow bays framed by promontories that align with the horsts. The alternating ridges and troughs in northern Malta expose BC to wave action, leading to fine sandy bays like Għadira Bay. Notably, in Gozo, only one beach, Ramla Bay, with its unique 'reddish' sand, interrupts the coastal scree slopes (MT: rdum) stretching from Marsalforn Bay's eastern headland to Daħlet Qorrot, marking a unique point where the BC and UGL layers meet near sea level. On some of these beaches, particularly in northern and northwestern Malta, Gozo, and Comino, remnants of aeolian landforms, such as sand dunes, can still be found. Notable beaches in Malta include Għadira (Mellieħa Bay), Ramla tat-Torri, Little Armier, Ramla ta' l-Armier, Ramla tal-Bir, Ramla tal-Mixquqa, and Ġnejna Bay. In Comino, sand dunes are present at Santa Marija Bay. In Gozo, ir-Ramla l-Ħamra hosts the largest sand dune system in the Maltese Islands.

4. Shore platforms: Along cliffs cut into the Globigerina Limestone, such as between Marsaxlokk Bay and St. Thomas Bay in Malta, shore platforms have formed due to differential erosion at lithological boundaries. At Miġnuna Point (Marsaskala), the LGL underlies harder layers of hardground and conglomerate, topped by the softer MGL. Wave action erodes the MGL marls more rapidly, causing the MGL to retreat and leaving a shore platform in the harder underlying layers. Other similar platforms can be seen at Xwejni Bay (Gozo) and Qammieħ Point (Malta). Shore platforms also develop in the UGL, where the erosion of a softer yellow marl layer exposes a more resistant yellow bed beneath. Notable examples include Delimara and Selmun in Malta and Għar Qawqla (near Marsalforn) in Gozo. Less common are shore platforms at the base of LCL cliffs, such as those at Maddalena and Buxieħ in Dingli, Għar Ħasan in Birżebbuġa, and between Xgħajra and Żonqor (Marsaskala). These LCL platforms form where a softer, gently dipping LCL bed is within the reach of storm waves, which erode the underlying layer, eventually causing the overlying LGL to collapse and creating a platform as the cliff face retreats. Where the soft LCL bed rises above the storm wave reach, platform formation ceases.

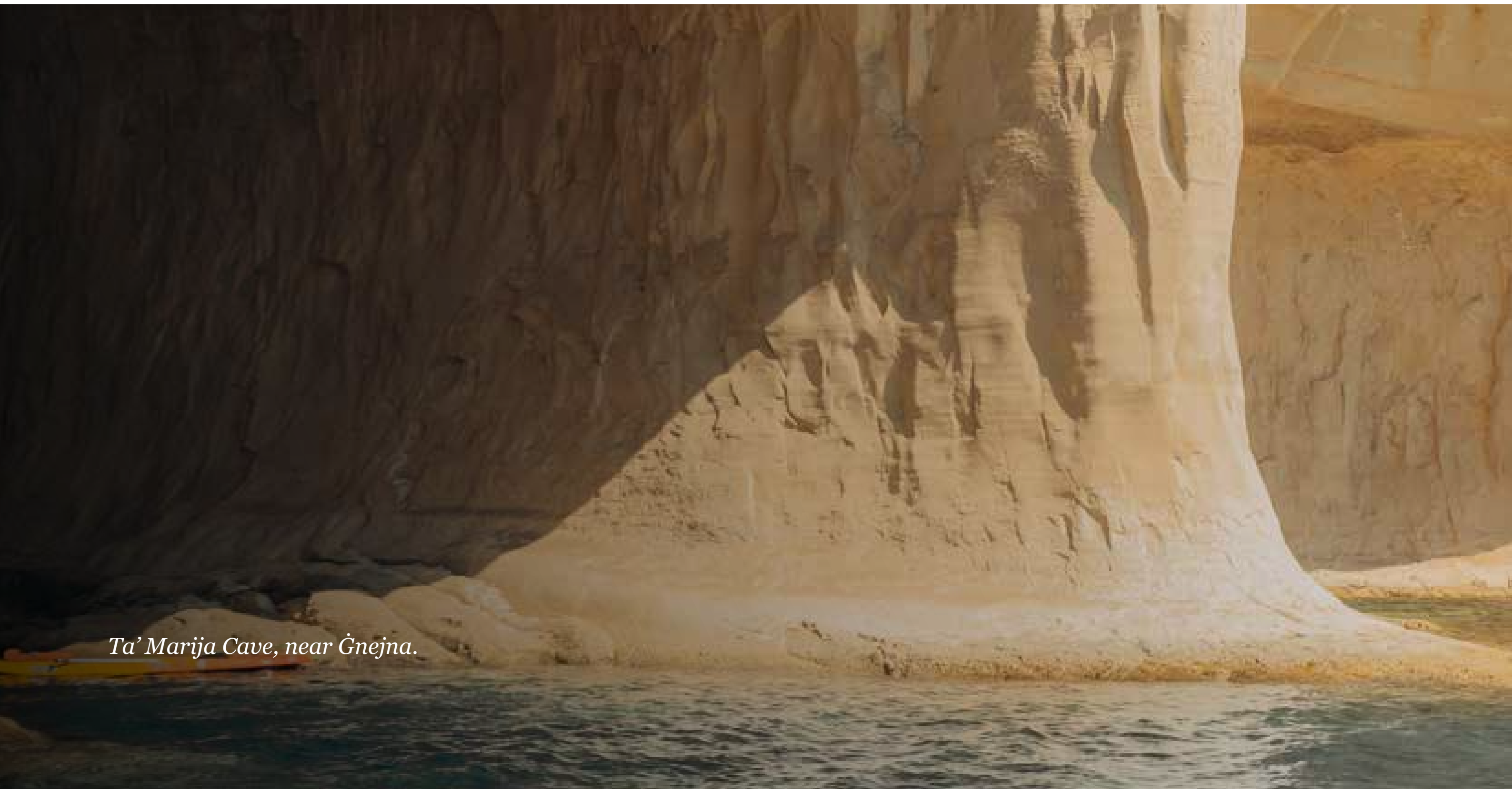
5. Scree slopes (MT: Rdum): Along the coastline from Fomm ir-Riħ to Ċirkewwa, a characteristic scree sloping morphology is observed, where large boulders of LCL detach from the upper plateaus, tumbling and sliding down across BC and UGL layers to reach the shore. Rainwater percolates through limestone fissures, reaching the clay below, which then becomes unstable. Faulting and

jointing in the UCL cause it to break up and descend onto the clay slopes. This process creates a shoreline bordered by boulder fields originating from the UCL uplands, with larger landslides occurring at the base of steep escarpments. This is visible at sites like Rdum id-Delli (Mellieħa), Ras il-Waħx (Manikata), and il-Karraba Headland in Għajn Tuffieħa (Malta).

6. Badlands: Coastal clay slopes in BC are characterized by steep gullies and deeply eroded valleys and best represented by the Karraba Headland in Għajn Tuffieħa, Selmun and Qammieħ Point along the western coast of Marfa Ridge. Some of these clay landscapes are colonised by steppe grasses, which slow down their erosion derived from gravitation-induced sediment transport.

7. Cliffs: Towering cliffs, ranging from 30 to 120 metres in height, comprise nearly half of the Maltese coastline. These dramatic cliffs define the landscapes of western and southwestern Malta, eastern Comino, and much of Gozo's coast. In Malta, vertical cliffs are primarily carved from the LCL, extending from Wied ix-Xaqqa (limits of Birżebbuġa) in the southeast to Fomm ir-Riħ (limits of Baħrija) in the west. At Għar Lapsi, the Magħlaq Fault reveals a fault plane, displacing the UCL by at least 230 metres downward to the south. This high-relief coastline is interrupted by lower-lying sections at Għar Lapsi and il-Magħlaq, where the fault has brought the UCL down to sea level. In Gozo, much of the coastline from Mġarr ix-Xini in the east, continuing clockwise to Ta' Ċenċ, Pinu Point, and Wied il-Għasri, consists predominantly of sheer vertical cliffs that expose the LCL.

8. Coves or sinkholes: Karst processes, influenced by the abundance of limestone across the Maltese archipelago, have led to the formation of unique coastal features, including semi-circular coves and sinkholes. These coves are classified into three main types: (1) solution subsidence structures that form by the collapse of karstic cavities and are now submerged by the sea, such as at Dwejra and Qawra (Gozo) and the Blue Grotto (Malta); (2) erosional circular coves, such as il-Ħofra l-Kbira and il-Ħofra ż-Żgħira (Delimara, Malta), which are created by differential erosion from waves acting on softer MGL marls under more resistant UGL layers; and (3) fault-bound circular coves, such as Ta' L-Imgħarrqa in Għadira Bay, where waves penetrate into fractures along UCL, eroding the softer GL to create circular coves.



Ta' Marija Cave, near Ġnejna.

9. Sea caves and arches: Sea caves are abundant along the coastline, typically forming where steeply dipping fractures or faults are present. Wave action gradually enlarges these weakened rock joints or fault planes into sizeable, circular caves or arches. When horizontal bedding is present, caves can extend up to 30 to 40 metres in width. In some cases, roof collapse has created a large blowhole, locally called a 'dragonara', at L-Aħrax on Marfa Ridge's eastern coast. Other famous sea caves include those near the Blue Grotto (Żurrieq) or Wied il-Mielaħ (Gozo). The caves on Comino have formed from a combination of limestone dissolution (karstification) along fractures and joints in UCL and marine erosion, which widened and tunnelled out these lines of weakness to form caves and tunnels, such as the Santa Marija Cave.

Other coastal caves located on elevated cliffs, such as Għar Ħasan, owe their formation to former wetter climate in the Quaternary period, which created elevated water table levels that saturated fractures, joints, and pores in the rock. In this saturated zone, water rich in dissolved carbon dioxide reacted chemically with the surrounding limestone or other soluble rocks, gradually dissolving it along lines of weakness, such as fractures and fissures. This process, known as chemical weathering, enlarges these pre-existing weaknesses and carves out cavities within the rock. As climate conditions shifted to a drier phase, water levels dropped, exposing these chemically weathered cavities to air. Over time, these areas of past saturation evolved into the caves we observe today, with their unique formations influenced by the original zones of chemical weathering along fractures and fissures.

Our coast's diverse landscapes are more than scenery; they are Malta's geoheritage, a shared and enduring memory of the Earth. Preserving these landscapes is not only about conserving their aesthetic value but also honouring the deep geological and geomorphological identity embedded in every cliff, beach and shore platform, which together enrich Malta's natural legacy.