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# Shore Platform Denudation Measurements along the Maltese Coastline

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## ABSTRACT

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Using an original rock profiling technique especially adapted to locally common smooth and irregular / deeply weathered (karstic) rocky shores, 38 base-line profiles were established at 19 rocky-shore sites to investigate surface-denudation characteristics exhibited by natural rock surfaces found on the Maltese coast. The latter were identified as being representative of actual or potential bathing platforms, thus offering a valuable alternative to otherwise scarce beach environments on the tourist rich Islands of Malta. Observations on shore surface denudation over a 3 – 5 year period were subsequently related to degree of exposure, erosion and weathering processes considered active at each site. Identification of distinct surface-denudation characteristics for sub-divisions within the Globigerina Limestone and similar surface-lowering rates for Lower Coralline Limestone and the Lower Globigerina Limestone sub-division were considered to qualify otherwise subjective interpretation of local bedrock resistance to marine erosion and weathering. The design of an innovative 'Rock Profiler', was identified as an improvement to traditional profiling techniques, allowing surface elevation measurements over both smooth and indented rock surfaces, achievements of more representative rock surface profiling over extended sample areas (with a 95 consecutive point line-transect), accurate assessments of rock surface micro-relief and of carrying out profiling independent of rock surface plane. This study provided for the first time, accurate and distinct surface-denudation rates for the main geological formations exposed on the Maltese coast, these being 1.38mm/yr for Upper Coralline Limestone, 9.16mm/yr for Middle Globigerina Limestone, 0.74mm/yr for Lower Globigerina Limestone and 0.77mm/yr for Lower Coralline Limestone.

**ADITIONAL INDEX WORDS:** *Rock profiler, Globigerina and Coralline limestone, rocky shore*

## INTRODUCTION

Rocky and sand coastlines, are subject to amplified land-use conflict due to increasing trends in coastal urbanisation and vacationing at coastal resorts. Poor consideration of management needs of low-lying rocky shores is reflected by a literature survey of coast-related research works presented in scientific journals and at international conferences addressing coastal management issues. Of 902 research works, only 0.33% (3) were identified as specifically addressing management aspects of low-lying rocky coasts. In comparison, 9.8% (88) works dealt with beach related issues while 6.2% (56) were concerned with bathing water quality.

This may be partly related to a preconceived idea that coastal recreation in general occurs only in connection with beaches, resulting in research work in this field being largely oriented to sand beaches and related environments. Coastal erosion works have also largely focused on beach studies and to a lesser extent on cliff recession with the only work related to low-lying rocky shores indirectly addressed in works investigating shore platform development or through development of shoreline management plans (e.g. in the U.K.) that dealt largely with coastal defence strategies and the protection of wildlife habitats (Sunamura, 1992, Davies *et al.,* 2004). General studies on integrated coastal management were also identified as failing to sufficiently consider recreational aspects of low-lying rocky shores. At the Mediterranean regional level for example, UNEP guidelines on Integrated Management of Coastal and Marine Areas (UNEP, 1995) make general recommendations with some specific reference to sandy beaches and cliffs but completely omit reference to accessible rocky shores.

Various national legislations consider general land-use issues that may be considered as having specific relevance to low-lying rocky shores. The 'Ley de Costas' (1988) of Spain for example, refers to rights of public passage over a 6m wide strip adjacent to the shoreline and to specified development that can take place in the first 100m inland from the shore (Montoya, 1990). However no specific reference is made to recreation-related management of accessible shores. Similarly, in Italy (as in many other Mediterranean countries) national coastal management policy includes reference to rocky coasts but aspects of recreational use are un-addressed.

A main aim of the rock shore profiling was to determine trends of surface denudation by erosion and weathering exhibited by the various rock types found on the Maltese coast and to relate such findings to exposure characteristics, rock type and ambient factors influencing these processes. Apart from largely inaccessible cliffs, *rdums* and limited beach areas, the natural Maltese coastline otherwise comprises generally accessible low-lying rocky shore suitable for bathing purposes. The identification of specific instrumentation suitable for measurement of surface denudation on low-lying rocky shores and collection of related base-line data, was therefore considered a valuable contribution to effective shoreline management of the Maltese Islands.

## METHODOLOGY

In total, 38 profiles were established at 17 rocky shore sites (Figure 1). The choice of sites ensured full representation of the various rock types exposed in the local coastal environment and reflect variable geomorphologic features representative of the Maltese coastline. Within a single coastal embayment, profiling was established on a particular geological formation at headland exposures, facing directly into the prevailing wind and wave action, as well as further inland in more sheltered areas. This ensured that within a single site, direct comparison of varying rates of surface denudation at the micro-scale could be subsequently made. The majority of sites were localised at the water's edge to represent the direct water/rock interaction. Several sites were also positioned above the mean water level but within the storm wave zone while others were located above direct storm wave impact but in a position still exposed to sea-spray and precipitation water run-off. The rock profiler was designed specifically to measure detailed line-profiles on a rock surface which, unlike clay/soil slope surfaces offers the opportunity of a non-movable base from which unlimited repeat measurements can be made.

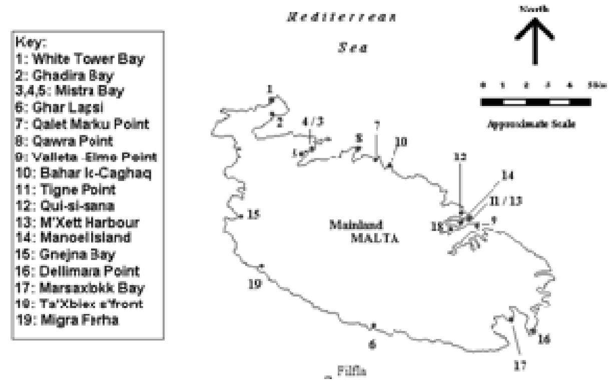

Figure 1. Rock profiling sites.

The *Rock Profiler* was made of brass-plated steel, incorporating an '*H'* shaped frame as the main supporting body (Figure 2). The rods forming the legs measured 34cm in length, with a smaller gauge 2cm stainless steel foot projecting from the end of each rod. Each foot fits into brass sleeves, which are permanently set into the ground for repeated measurements, using a quick setting, epoxy glue. Ninety-five 34cm-long brass needles slide up and down through sleeves bored 2mm apart in the horizontal of the main frame, measuring 6.3cm deep, 47.8cm long and 1.3cm wide. The brass needles are fixed in position by a series of plastic screws, designed so as to allow tightening using only finger pressure. A template consisting of a length of light metal bar with stainless steel feet fixed at the exact distance apart as found on the main profiler body, was also designed for the purpose of marking out spots to be drilled in the rock surface. Care was taken to ensure that the receiving brass sockets were carefully set so as not to present a hazard in the form of protrusions above the rock surface. The template was also used to test the 'fit' of the drilled site prior to permanently setting the sleeves into the ground, making sure that the sleeve receiving holes were drilled precisely enough to prevent excessive widening.

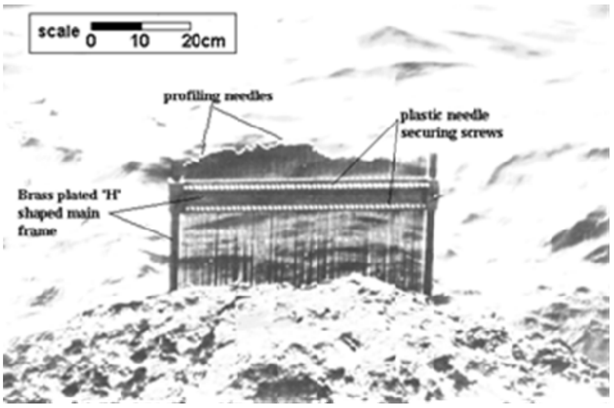

Figure 2. The 'Rock Profiler' (*designed by University of Durham, U.K.)*

## RESULTS

Of the 38 base-line transects, eight were lost by natural causes and human disturbance (storm dislocation of brass sleeves at Dellimara and Fort. St. Lucian sites and through concrete surfacing, at Gnejna, Ta' Xbiex and Migra Ferha sites (Figure 1). Due to the very slow rate of surface denudation exhibited by rocky shores, ranging between 0.01cm - 0.15cm/year (Robinson, 1977b; Carter, 1988; Sunamura, 1992) three profile records were collected at each of the sites examined over a five year period. This pattern of profiling was adopted to allow description of a 3 - 5 year surface denudation pattern followed by a one-year measurement to confirm or otherwise consistency of annual surface lowering rates. Figures 3 - 6 represent a selection of the thirty rock surface profiles produced for all study sites, describing the various rock types evaluated on the Maltese coastline. Surface denudation rates, related weathering / erosion processes and wind exposure conditions of each site are presented in Table 1.

## DISCUSSION

Pethick (1984) identified rock hardness, structural weaknesses, coastline configuration, rock solubility, cliff/platform height and the nature of wave attack as the main factors controlling erosion of cliffs and low-lying rocky shores. In discussing coastal morphology, the author further identified coastal erosion processes (quarrying or removing of loose rock by wave action, abrasion by sands and shingle, and bio-erosion) and rock weathering (including solution of calcareous rock) as the prime agents. Very few techniques have been developed to measure the main processes identified with erosion and weathering of rocky coasts (Pethick, 1984; Carter, 1988; Sunamura, 1992). The most frequently used method for measuring shoreline erosion rates has to-date involved the use of the 'micro-erosion meter' (Mottershead, 1982; Robinson, 1977b), where measurements have indicated a broad range of erosion rates varying between 0.01mm to 25mm/year. Carter (1988) has attributed this variation mainly to the different resistance exhibited by rocks depending on their lithology, structure and incident wave conditions.

Literature on local geology (House *et al*., 1961; Schembri & Baldacchino, 1992) has to date made only brief and subjective reference (based mainly on visual observations of coastal geomorphological features) to rock erosion and weathering properties exhibited by local rock formations. Lower Coralline Limestone has been described as a hard semi-crystalline rock,

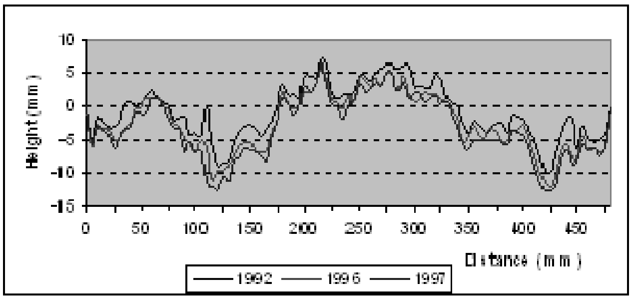

Figure 3. Upper Coralline limestone (*Mtarfa Member*) horizontal rock profile (1.1) at White Tower Bay.

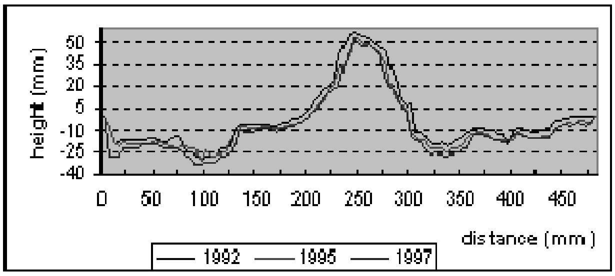

Figure 4. Fig 4: Lower Coralline (Xlendi Member) rock profile 8.2 Qawra Point, north coast of Malta.

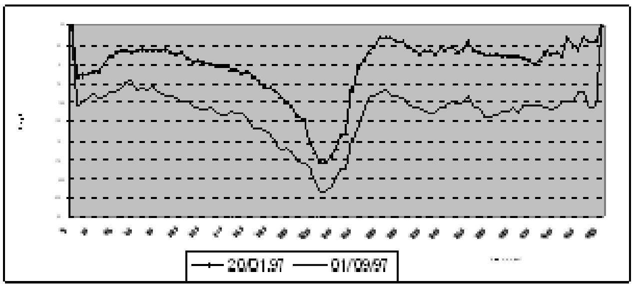

Figure 5. Fig 5: Middle Globigerina Limestone rock profile 15.1, Gnejna Bay, west coast of Malta.

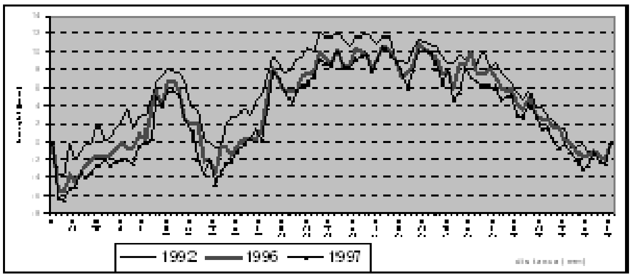

Figure 6. Lower Globigerina Limestone rock profile 9.3, Fort St. Elmo Point, north coast of Malta

giving rise to various morphological features such as deeply pitted karstic features which have been attributed to chemical and sub-aerial weathering (De Keteleare, 1991). Similarly, Globigerina Limestone has been collectively described as giving rise to smooth coastal strips, large solution features and being more easily eroded than the Lower Coralline Limestone (House *et al*., 1961) without distinction of surface-lowering properties exhibited by the Formation's sub-divisions (Upper, *Middle* and *Lower* Globigerina Limestone strata). As with the Lower Coralline Limestone, the Upper Coralline Limestone has also been described as being semi-crystalline and associated with karstic pavements but being softer than its corresponding Lower Coralline form (Pedley, 1978). Based on the results obtained by this study, more specific observations may now be made. Table 1 presents the overall rock profile results, describing surface denudation rates exhibited by the four main rock-types examined under different exposure conditions and representing a range of shoreline features encountered on the Maltese coast.

As observed by a number of authors (Spencer, 1981; Sunamura, 1992) and as identified by this study, a considerable range of surface lowering values may be observed at each site, reflecting inter-annual variation in surface-lowering rates. This demonstrates the high variability possible in point lowering measurements at the micro-scale and the considerable spatial variation in surface-lowering rates even on the same bedrock and at the same profiling site.

From observations made, a substantial distinction of erosion and weathering properties was identified for sub-divisions within the Globigerina Limestone (see for example, surface lowering records for Gnejna Bay shore platforms, (Table 1). In addition, the rock profiling results described very similar mean surface-lowering rates for coastal Lower Coralline Limestone and *Lower* Globigerina Limestone rock surfaces (0.77mm/yr and 0.74mm/yr respectively). This has for the first time qualified the otherwise sweeping concept held locally that Globigerina Limestone is much more easily eroded than Lower Coralline Limestone (Paskoff & Sanlaville, 1978; House *et al*., 1961). In identifying Upper Coralline Limestone as less resistant to erosion and weathering than both Lower Coralline Limestone and the *Lower* Globigerina Limestone sub-division, this study has also confirmed otherwise general observations regarding increased susceptibility to weathering by Coralline Limestone shores due to the vertical formation and frequently weak-bedded nature of the Upper Coralline (De Keteleare, 1991) and their mainly carbonate composition.

The order of resistance to erosion and weathering processes identified for the different rock types examined was also observed to be in accordance with known lithological properties (*Dunham et al., 1955 and DeKetelaere, 1991*). In this context, the results for shore platform profiles also concurred with the findings of Sunamura (1992) who considered lithological resistance of the exposed bedrock as one of the prime factors influencing platform formation (see for e.g. site 15 (Gnejna), where the different erosion and weathering resistance properties of the *Middle* and *Lower* Globigerina Limestone surfaces were clearly reflected in the mean rate of surface denudation changes recorded for the respective Globigerina Limestone Divisions (Table 1). A stepped sequence of *Lower* and *Middle* Globigerina Limestone shore platforms identified during field observations at Gnejna and Dellimara (sites 15 & 16 respectively) were also reflective of different Divisional lithological properties. Stepped shore platforms in Malta have also been described by Paskoff & Sanlaville (1978) who suggested that as a consequence of variance in resistance to erosion (exhibited by the Globigerina Limestone sub-divisions), marine erosion is responsible for removing the less resistant layers to expose a shore platform surface composed of the more resistant *Lower* Globigerina Limestone division.

No correlation was evident between the direction of exposure and mean surface-lowering rates recorded. Within the Upper

Coralline Limestone (Mtarfa Member) group of profiles for example, profile 15.3 at Gnejna Bay having a W/WNW exposure and profile 1.2 (at White Tower Bay, (Table 1) with a northerly exposure, exhibited identical mean surface denudation rates of 1.82mm/yr (Table 1). In addition, within the *Lower* Globigerina Limestone sub-group, profiles with a NNW/N/NE exposure (sites 9, & 10) were observed to exhibit a lower mean surface down-wear rate (0.66mm/yr.) than profiles at sites 11& 14, (mean surface-lowering rates of 0.84mm/yr.) where exposure was oriented to the less prevalent NE direction. In addition, comparison of exposed with sheltered sites, mean surface-lowering rates were found to be significantly higher only within the Upper Coralline (*Tal-Pitkal Member*) Limestone profiles where *exposed* sites (3.1, 3.2, , 5, & 6.1) described a mean surface denudation rate of 1.29 mm/yr and *sheltered* sites (4, & 6.2) exhibited a lower mean down-wear rate of 0.31mm/yr. Conversely, in the Lower Coralline (Xlendi Member) Limestone profiles, the mean down-wear rates for sheltered and exposed sites were identical (0.77mm/yr) and in the *Lower* Globigerina Limestone profiles, the difference was minimal (0.74mm/yr and 0.68mm/yr). This suggested that on the Maltese coast, weathering processes appear dominant in determining rock-surface denudation and that no correlation appears to be present between site exposure and mean surface lowering rate.

The greater susceptibility to wave impact of vertical rock faces at the coast was illustrated by significant variation in mean surface lowering-rates observed for horizontal and vertically oriented profiles within the same rock type sub-group and having the same exposure characteristics (e.g. *horizontal* profile 1.1, mean down-wear rate of 0.5mm/yr. and *vertical* profile 1.2, with a mean down-wear rate of 1.82 mm/yr - see Table 1). The observation by Mottershead (1982) that once pitted, a rock surface will tend to retain water which will enhance weathering, was also supported by the higher mean surface-lowering rates recorded by this study for Upper Coralline Limestone rocky shores characterised by deeply pitted, karstic surfaces (see profiles 1.2 at White Tower Bay and 8.1 at Qawra Point ).

Table 1. Summary Table for all rock profiles, identifying mean surface lowering rates and weathering / erosion related criteria.

| **Profile N$^{o}$.** | **Rock type sub-division** | **Mean surface lowering rate (mm/yr)** | **Weathering** |  | **Mechanical erosion** |  | **Bio-logical** | **Human impact** | **Exposure** |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Physical | Chemical | Abrasion | Quarrying |  |  |  |
| **Upper Coralline Limestone** |  |  |  |  |  |  |  |  |  |
| 1.1 | *Mtarfa* | 0.5 | X |  | X | X |  |  | N |
| 1.2 | *Mtarfa* | 1.82 |  | X | X | X |  |  | N |
| 2 | *Mtarfa* | 1.70 |  | X | X | X | X |  | NE |
| 15.3 | *Mtarfa* | 1.82 |  | X |  | X | X |  | W/WNW |
| 3.1 | *Tal - Pitkal* | 1.54 | X |  |  | X |  |  | ENE |
| 3.2* | *Tal - Pitkal* | 1.23 | X | X | X | X |  | X | ENE |
| 4 | *Tal - Pitkal* | 0.27 | X |  |  |  |  |  | Sheltered |
| 5 | *Tal - Pitkal* | 1.22 |  | X | X | X |  |  | NE |
| 6.1 | *Tal - Pitkal* | 1.13 | X | X |  | X |  |  | SW/S/SE |
| 6.2 | *Tal - Pitkal* | 0.34 |  |  |  | X |  |  | Sheltered |
| **Lower Coralline Limestone** |  |  |  |  |  |  |  |  |  |
| 7.2 * | *Xlendi* | 0.62 | X | X |  | X |  | X | NW/NE |
| 7.3 | *Xlendi* | 0.48 | X | X |  | X |  | X | NW/NE |
| 8.1 | *Xlendi* | 0.77 |  | X |  | X | X |  | NW/N/NE |
| 8.2 | *Xlendi* | 1.2 | X | X |  | X |  |  | NW/N/NE |
| 8.3 | *Xlendi* | 0.68 | X | X |  |  |  | X | Sheltered |
| 8.4 | *Xlendi* | 0.85 | X | X |  |  |  | X | Sheltered |
| **Globigerina Limestone** |  |  |  |  |  |  |  |  |  |
| 9.1 | *Lower* | 0.57 |  |  |  | X |  |  | NNW/N/NE |
| 9.2 | *Lower* | 0.49 |  |  |  | X |  |  | NNW/N/NE |
| 9.3 | *Lower* | 0.54 |  |  |  | X |  |  | NNW/N/NE |
| 10.1 | *Lower* | 0.76 |  | X |  | X |  | X | NNW/N/NE |
| 10.2 | *Lower* | 0.94 | X | X |  | X |  | X | NNW/N/NE |
| 10.3 | *Lower* | 0.63 |  | X |  | X |  |  | NNW/N/NE |
| 11.1 | *Lower* | 0.63 | X |  |  | X |  |  | NE |
| 11.2 | *Lower* | 0.96 | X |  |  | X |  |  | NE |
| 12 | *Lower* | 1.09 | X | X |  | X |  | X | N/NE |
| 13 | *Lower* | 0.68 | X |  |  |  |  | X | Sheltered |
| 14 | *Lower* | 0.96 | X |  |  | X | X |  | NE |
| 15.2 | *Lower* | 0.60 | X | X |  | X |  |  | W/WNW |
| **Globigerina Limestone** |  |  |  |  |  |  |  |  |  |
| 15.1 | *Middle* | 9.16 | X |  |  |  |  |  |  |
| 16/17 | *Middle* | 13 (approx.) |  |  |  |  |  |  |  |

**Key:** X identifies influence of weathering or erosion process; * For profiles 3.2 & 7.2 which spanned natural & artificial rock surfaces, the mean erosion rate was reported separately for both rock types.

Results obtained also imply that erosion of coastal rock formations may be strongly influenced by prevalent storm conditions. The mean surface lowering rates measured on northerly exposed sites between 1992 – 1995, were observed to be lower (on occasion being half the magnitude) of the mean surface lowering rates measured for the same sites between 1995 – 1997. At Bahar Ic-Caghaq for example (site 10) profile 10.2 exhibited a mean surface-lowering rate of 0.45mm/yr. between 1992 - 1995 and 1.66mm/yr. between 1995 - 1997. Similarly, at profile 10.3, a mean surface-lowering rate of 0.49mm/yr. was recorded between 1992 - 1995 and 0.83mm/yr. between 1995 - 1997. This trend may be associated with northerly gale storms recorded for this period by the Malta Meteorological Office reflecting a 1 : 4 ratio of storm-events occurring between 1992 – 1995 and 1995 – 1997. Similar observations have also been made by Robinson (1976), who reported that erosion rates at the coast are highly variable in magnitude and may be caused by sporadic, extreme events.

The relatively high mean surface-lowering rates observed in flat rock pans or ponds (see Figure 4, profile 8.2, Qawra Point) were considered to suggest a strong influence of physical corrosion by salt crystallisation within surface rock pores. This may be related to the particularly high summer temperatures (Carter, 1988) and seawater salinity in the Mediterranean, the latter averaging about 36% and increased permeability of local Limestones that have been reported to favour weathering by corrosion (Pethic, 1984).

## CONCLUSIONS

Rock-surface denudation rates were identified (in order of increasing resistance to erosion and weathering processes) as, *Middle* Globigerina Limestone with a mean surface-lowering rate of 9.16mm/yr, (*least resistant*); Upper Coralline (*Mtarfa & Tal-Pitkal Member*) Limestone surfaces - mean surface-lowering rate of 1.38mm/yr; Lower Coralline (*Xlendi Member*) Limestone surfaces - mean surface-lowering rate of 0.77mm/yr; *Lower* Globigerina Limestone - mean surface-lowering rate of 0.74mm/yr. (*most resistant*).

A general mean surface-lowering rate for limestone, has been identified by various authors to lie within the range of 0.15 - 4mm/year. Results obtained by this study for local limestone surface-lowering rates (0.74 - 1.38mm/yr) were observed to fall within the same range reported by other authors (Trudgill, 1976; Robinson, 1977b; Spencer, 1981; Mottershead, 1982; Carter, 1988). The exception to the above was the mean surface-lowering rate observed for the *Middle* Globigerina Limestone sub-division that (at 9.16mm/year) surpassed the maximum surface-denudation rates on Limestone observed in other parts of the world.

While direct comparison with other localities is difficult due to the broad range of factors involved, it is possible to make general observations regarding what has emerged as a generally higher rock surface-lowering rate on Maltese limestones when compared to those in northern countries such as for example, Ireland and Wales in the UK. In part, this may be related to a combination of the high temperatures and rock permeability found in Malta which has been described by Pethick (1984) as favourable conditions for enhanced weathering by corrosion. These observations are also supported by the generally higher rock surface lowering rates reported by Trudgill (1976) for gently sloping limestone shores in the Indian Ocean. In this context, De Keteleare (1991) also stressed the strong impact of solution processes on rock weathering at the Maltese coast.

Based on the rock profiling results obtained and earlier discussion on erosion and weathering of sloping rocky shores and shore platforms, local environmental factors influencing surface-denudation of rocky shores were identified Under the influence of the factors described in Table 1, it is suggested that the dominant surface denudation processes active on local rocky-shores are mechanical wave erosion, (largely in the form of quarrying due to the general absence of abrasive shingle at the coast), solution and salt-crystallisation. Human disturbance and biological activity were also considered to contribute to overall rock surface-lowering but in a secondary and less influential role.

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