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Letter

# Downwearing rates of vertical limestone surfaces in the intertidal zone (Gulf of Trieste, Italy)

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ABSTRACT

In 2007, we installed seven micro-erosion meter stations on a vertical limestone slab located in the intertidal zone in the Gulf of Trieste (Italy) in order to observe rock surface changes at elevations ranging between −0.75 m and +0.75 m m.s.l. (Furlani et al., 2010). In this paper, we present the micro-erosion metre (MEM) data for most months between February 2008 and May 2013 and the traversing micro-erosion metre (TMEM) data collected twice a year since 2007. The MEM and TMEM data were consistent and indicated that the mean lowering rate ranged between 0.007 mm/yr and 0.205 mm/yr and −0.001 mm/yr and 0.260 mm/yr, according to the elevation of the stations. Maximum downwearing rates were observed in the mid-lower intertidal zone and decreased upward and downward. The natural trend of erosion started in 2010, after 2 years of exposure, when the slab, formerly smoothed and not colonized by marine organisms, started to be acclimated to the local environment. After 2010, the erosion rate increased to a maximum of 0.31 mm/yr. This value can be more representative for long-term studies and is similar to the downwearing rates locally collected on natural limestone surfaces.

This dataset represents the first collection of downwearing rates mainly measured using MEMs, but also TMEMs on vertical limestone surfaces in an intertidal zone and provides interesting new information for addressing the debate on notch genesis and development. The shape of a tidal notch has been found to be consistent with the distribution of erosion rates along the slab, even if the present-day notch was not surveyed in the Gulf of Trieste due to the local tectonic subsidence.

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## 1. Introduction

Limestone downwearing rates on vertical surfaces in the intertidal zone are of great interest because they are closely related to the development of marine notches. The micro-erosion metre (MEM) and the traversing micro-erosion metre (TMEM) have been successfully used to study limestone erosion rates in coastal environments. Moreover, the use of MEM and TMEM standardises downwearing rates in Anglo-Saxon countries (Swantesson et al., 2006), and other areas of the world (Cucchi et al., 2006; Furlani et al., 2009; Stephenson and Finlayson, 2009), and is also related to notch development (Moses, 2013) in tropical areas. The large number of papers and reports concerned with MEM and TMEM data is evidence of a high interest in intertidal limestone erosion, but little is known about the downwearing rates of vertical surfaces, mainly because of the technical difficulties involved when the instruments are used on steep slopes. Studies concerning downwearing rates on shore platforms, however, have been used on both as long-term monitoring (e.g., Trudgill, 1976; Kirk, 1977; Gill and Lang, 1983; Stephenson and Kirk, 1998; Porter et al., 2010a, 2010b, 2010c) and recently as short-term (diurnal) monitoring (Stephenson et al., 2004; Trenhaile, 2006; Furlani and Cucchi, 2007; Gomez-Pujol et al., 2007; Porter and Trenhaile, 2007). A number of papers have also focused on the Adriatic karst area (e.g., Torunski, 1979; Forti, 1980; Cucchi et al., 2006) and the Adriatic coastal area (Furlani et al., 2009). Based on a year-long dataset, Torunski (1979) found increasing rates of erosion at increasing depths (ranging from 0.07 mm/yr to 1.114 mm/yr), resulting in the development of a biogenic intertidal notch. He also observed increasing erosion rates during the summer months. Close to the same study area, Furlani et al. (2009) suggested higher downwearing rates during autumn, with downwearing rates ranging from 0.145 mm/yr to 0.349 mm/yr.

The aforementioned technical difficulty of collecting TMEM data on coasts with high inclines has generally prevented the installation of measuring stations on horizontal surfaces. The rock removable slab (RSS) method suggested by Furlani et al. (2010), however, has allowed measurements to be made on laboratory-made rock surfaces that are vertically set in a natural environment and then later removed to collect measurements.

The aim of this paper is to present and discuss more than 5 years of measurements collected on a limestone slab set vertically in a sheltered site along the coast of the Gulf of Trieste, Italy (Fig. 1), first

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described by Furlani et al. (2010). In particular, we aim to (1) assess the differences in limestone downwearing rates inside the intertidal zone, (2) evaluate the differences in total erosion rates collected using MEM and TMEM, (3) assess monthly or seasonal changes in erosion rates collected using MEM, and (4) assess the usefulness of the RSS method for studies of coastal limestone erosion.

## 2. Study area

The limestone slab was located in the small harbour of the Miramare Castle in the Marine Reserve of Miramare in the Gulf of Trieste in the Northeastern Adriatic Sea (Italy, Fig. 1). Climatological data for the study area were provided by Stravisi (2003). The mean annual rainfall in Trieste from 1961 to 1990 was 1015 mm/yr. The minimum mean value was recorded in July (70 mm), and the maximum was recorded in November (105 mm). Storms are more frequent at the end of the summer and in the autumn. The average annual temperature in the same period was approximately 15.4 °C. The hottest month is August (24 °C), whereas the coldest month is January (below 6 °C). The average relative humidity is 63%. Mean sea temperature is 16.6 °C, and it ranges between 9 °C and 11 °C, with a peak in August (24 °C), even though near coastal spring temperatures remain constant throughout the year (about 13 °C).

The wind climate is characterised by a prevalence of first quadrant winds, mainly from the east–northeast direction (Bora). South-easterly winds (Scirocco) are significant because of the long geographical fetch (over 800 km). Tides are semidiurnal, with a mean spring tide value of 0.86 m in Trieste and a mean neap tide value of 0.22 m. The concomitance of spring tides, seiches, south-easterly winds, and low atmospheric pressure can cause the sea level to rise by 1.60 m (locally called *acqua alta*). Seawater salinity is higher in winter than during the summer and ranges between 34 and 39 psu (data from the Miramare oceanographic buoy). Large differences in salinity are registered during the floods of the largest rivers, mainly in the Northern sector of the Gulf of Trieste. Some very small submarine springs have been recognized close to the studied stations. Frost is rare and affects only the most sheltered areas (Stravisi, 2003).

The coast of the Gulf of Trieste is characterised by the presence of submarine springs, as reported by the Regione Autonoma Friuli Venezia Giulia and Servizio Geologico (2008). In the Gulf of Trieste, the outflow (Cucchi and Zini, 2007) is mainly connected to the submarine springs related to the Timavo River (30 $m^3/s$), which discharges water from a large subterranean karstic area (about 900 $km^2$), and the Isonzo River (134 $m^3/s$).

The total heat flux from the sea is about 20 $W/m^2$ during the spring and summer and increases to 110 $W/m^2$ during the autumn and winter (Stravisi and Crisciani, 1986). It is balanced by an annual mean meridional flux. The strong influence of river runoff means that the northernmost sector of the Adriatic Sea can be considered to be a heat sink and a basin of dilution (Stravisi and Crisciani, 1986).

An estimate of wave energy for the northern Adriatic area in the form of $H^2T^2$ (H and T corresponding to the significant wave height and period) was obtained using the complete series of 3-hour measurements from 2000 to 2003 available from the Rete ondametrica nazionale — Agenzia per la protezione dellambiente e per i servizi tecnici RON-APAT (Fontolan et al., 2007) wave gauge located offshore at Ancona (Latitude 43,3704600, Longitude 13,3001300). The annual value is 15.61 $m^2s^2$.

Schneider (1976) provided a complete overview of the intertidal zonation on limestone coasts, while Torunski (1979) studied the biological factors of erosion in the Adriatic Sea and in the southern sector of the Gulf of Trieste. Different associations of red algae, brown algae, and epilithic and endolithic chlorophytes (e.g., *Fucus virsoides*, *Enteromorpha*, *Ulva lactuca*, and *Ulva rigida*) occur below the mean sea level. From the mean sea level to the mean high water of spring tides, the algae are partly replaced by a rich faunal community, composed of *Chthamalus stellatus*, *Mytilus galloprovincialis*, *Patella* spp., *Monodonta turbinata*, and associations of epilithic and endolithic cyanophytes, which can be found up to the extreme high water of spring tides in exposed sectors of the coast. A decrease in the cold species has been observed recently, probably because of climate change. The faunal community accounts for the vegetal changes, and *Patella caerulea* or *M. turbinata* have been observed in association with young algae. These changes in substrate (high temperature and decreasing faunal coverage) in the mediolittoral zone are probably causing variations of the epilithic and endolithic cyanophyceae and are possibly affecting erosion rates.

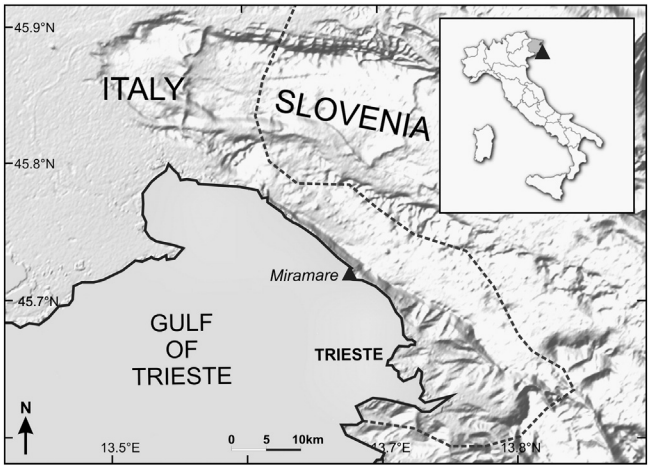



**Fig. 1.** Location of the MEM site at Miramare, Gulf of Trieste, NE Adriatic Sea (Italy).

## 3. Material and methods

Limestone-lowering rates were measured using both MEM, following High and Hanna's (1970) instructions, and an analogic or digital TMEM (aTMEM or dTMEM), as described by Trudgill et al. (1981). The instruments were equipped with three specially shaped supports that adhere to three titanium studs (two semi-spherical and one flat shaped) that were fixed into the limestone slab. The exact relocation of the fixed studs was derived from the configuration called the Kelvin clamp principle. The MEM used in this project was equipped with a centesimal-resolution dial gauge (Fig. 2b) and was only capable of collecting one measure for each station. The dTMEM was equipped with a millesimal-resolution electronic dial gauge. Digital readings were directly downloaded on to a laptop computer (Stephenson, 1997). Using this configuration allowed a large dataset to be obtained, with up to 238 measurements at a bolt site. Due to the large number of sites actually monitored (more than 600 stations all over the Mediterranean area), we decided to consider only 25 readings from each station. Even if the number of readings was near the minimum required for the measured erosion rates (10 readings), as suggested by Trenhaile and Lakhan (2011), there was a need to measure very quickly in order to leave the slab as much time as possible in its operating vertical position. For the same reason and to speed measurement operations, MEM was used when the tide was high or rising or when the slab was partially submerged. Sometimes the number of readings was reduced because organisms covered the slab and prevent measurements. A calibration steel base was used to check the instruments before every measurement session. The electronic dial gauge had a resolution of 0.001 mm, while the error, determined by the manufacturer (Mitutoyo), was $\pm$0.003 mm. Readings below 0.010 mm must be considered with caution (Stephenson et al., 2004). To reduce temperature-related errors, the instrument was set in equilibrium with air temperature before use. Probe erosion due to measurements was estimated using two different methodologies: (1) repeated readings on a test block, which revealed a

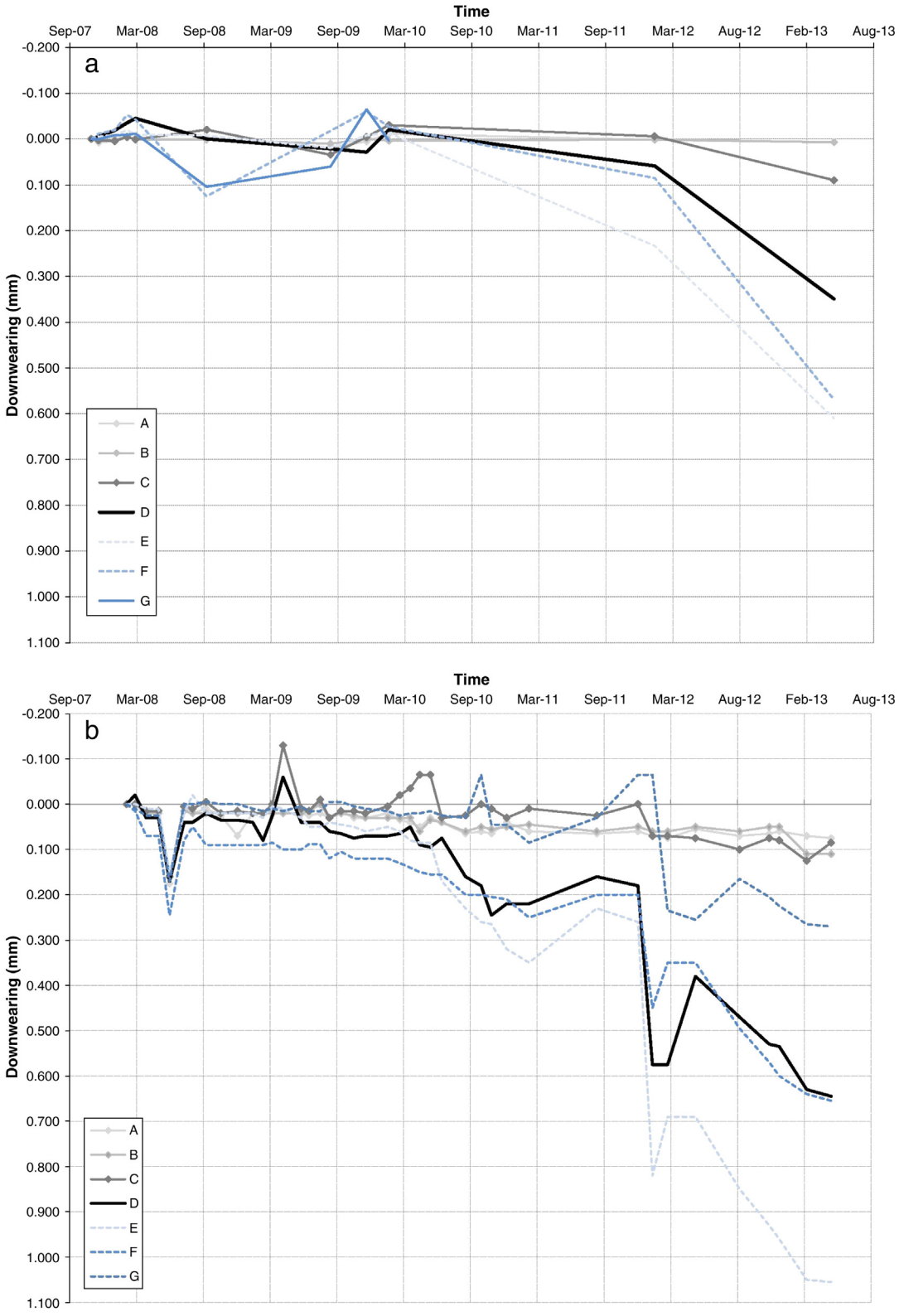



**Fig. 2.** Limestone surface change during the measurement period of each bolt station. a) Measurements collected using the TMEM; b) measurements collected using the MEM.

probe erosion of 0.003 mm after 100 measures; and (2) through visual microscopic analysis of 20 samples of rock touched by the probe and 20 others untouched by the probe (this was performed by Prof. Mauro Tretiach of the Department of Geobotany of the University of Trieste).

The RRS method for studying lowering rates in the intertidal zone has been fully described by Furlani et al. (2010). It allows measurements to be made of the lowering rates on vertical rock surfaces. It consists in a rock slab vertically set in the intertidal zone. The slab consists of a smooth limestone surface removed from a limestone quarry located 7 km from the observation site. The slab was removed using mechanical cutting, so initially it was not colonized and naturally weathered and roughened. It consisted of light grey, bioclastic Upper Cretaceous limestone with a grainstone texture and contained several small Rudist's

fragments (Radiolitidae). The physical and mechanical properties of the studied limestone were provided by Cucchi and Gerdol (1985), including the following characteristics: Porosity lower than 5%, a specific gravity of 2.63 kg/m$^3$, an imbibition coefficient of 11.8%, a compression breaking load of 1755 kg/cm$^2$, a tensile strength of 151 kg/cm$^2$, a flexural strength under concentrated load of 200 kg/cm$^2$, a thermal linear expansion coefficient of 0.0043 mm/ml/°C, impact resistance of 34 cm, and a wear resistance of 3.37 mm.

The limestone slab was 1.80 m long (the same maximum amplitude of the local tidal range in order to measure erosion rates in the whole intertidal zone), 0.15 m wide (micro-erosion metre stations are 0.1 m large) and 0.02 m thick (a larger thickness would make it too heavy to remove the slab for measuring operations). It was vertically set in the intertidal zone (Fig. 3). No bend or warp could occur on the slab, particularly around the stations, since the slab was located in a very sheltered area.

The physical/chemical and lithological properties of the studied limestone were the same as those of the limestone along the coasts of the Gulf of Trieste. The microtopography of the slab differed from the topography of the natural outcrops, however, since natural outcrops are rarely perfectly smooth. The slab was fixed on a vertical wall inside the small harbour of the Miramare castle, which is a well-protected site. It could be easily removed from the operating position, avoiding the use of TMEM in a vertical position.

The stations were set at different heights on the slab: +0.75 m (A), +0.5 m (B), +0.25 m (C), 0.0 m (D), −0.25 m (E), −0.5 m (F), and −0.75 m (G), as described in Fig. 3. The stations were submerged for increasing periods decreasing in altitude: A, 1 day/yr; B, 10 days/yr; C, 93 days/yr; D, 159 days/yr; E, 269 days/yr; F, 335 days/yr; and G, 360 days/yr.

According to local weather and tidal conditions, measurements on the limestone slab were generally made every month. Readings were usually collected during low water in order to minimize the change in conditions of the stations located below sea level at the moment of measuring. Measurements were made in a very short timeframe (an average of 20 min plus 10 min for the preparation of the instrument, but often the lower stations are not measured) close to the site, and no thermal variations or other biotic or abiotic variations occurred when the slab was removed from the operating position. The slab's low porosity prevented the accumulation of salt in pores, and no wedging from crystallization was observed.

## 4. Results

The limestone slab was installed in October 2007. TMEM measurements started in November 2007, while MEM measurements started in February 2008. The duration of the measurement record (Table 1) was 1900 days for the MEM and 1992 days for the dTMEM. Last measures with the aTMEM were collected in September 2012. The instrument was damaged soon thereafter, and it became impossible to collect new readings.

The station code, elevation (m m.s.l.), number of days during which the station was submerged during the year, and the total lowering and the mean lowering rates evaluated with MEM, aTMEM, and dTMEM have been summarised in Table 1.

MEM data were collected to measure most months from February 2008 to May 2013 (42 times in 64 months, which is an average of about every 6 weeks). Digital TMEM data were only periodically collected (18 times between November 2007 and May 2013, which is an average of about every 4 months, but they were only collected 10 times in correspondence to all the stations, so these data were collected an average of every 6 months overall) (Fig. 2a). Unfortunately, some measuring points located below the mean sea level were periodically covered by algae or other organisms, which partially prevented measurements being made.

During the study period, the stations experienced downwearing at different rates according to their elevation (Fig. 3). Data collected using MEM and TMEM showed a similar trend of erosion related to the altitude above or below mean sea level (Table 1). The mean erosion rates were lower above the mean sea level, from 0 mm/yr (station A, aTMEM) to 0.22 mm/yr (station C, aTMEM), with respect to the part of the slab laying below the mean sea level, where values ranged between 0.064 mm/yr (station D, dTMEM) and 0.26 mm/yr (station E, aTMEM). Higher lowering rates were measured at about −0.25 m below the mean sea level.

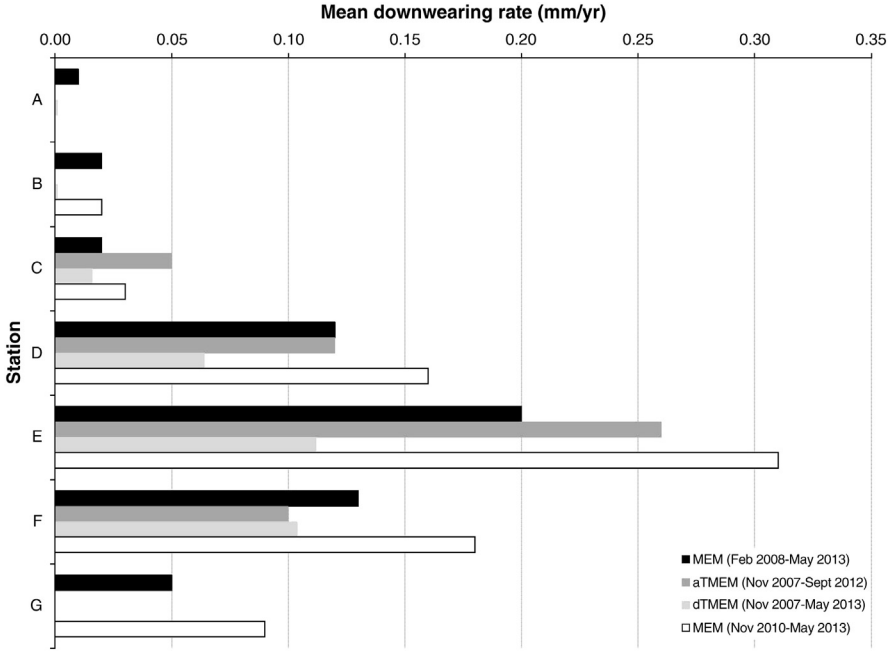



**Fig. 3.** Comparison between total erosion observed using the MEM (February 2008–May 2013), MEM (November 2010–May 2013), aTMEM (November 2007–September 2012) and dTMEM (November 2007–May 2013) of each bolt station on the limestone slab.

**Table 1**
Downwearing rates collected during about 5 years with the MEM, aTMEM and dTMEM on the vertical limestone slab. In the table the interval of measurement between the first and the latter measures and the number of surveyings with the three instruments are reported. 1) Name of the station; 2) height above or below mean sea level (m m.s.l.); 3) days of submersion of each station (day per yr); 4) total downwearing observed with MEM (mm); 5) mean lowering rate calculated with MEM (mm/yr); 6) total downwearing observed with MEM in the period between November 2010 and December 2012 (mm); 7) mean downwearing rate calculated with MEM in the period between November 2010 and December 2012 (mm/yr); 8) total downwearing observed with aTMEM (mm); 9) mean downwearing rate calculated with aTMEM (mm/yr); 10) total downwearing observed with dTMEM (mm); and 11) mean downwearing rate calculated with dTMEM (mm/yr).

| Type of instrument | | | MEM | | | | aTMEM | | dTMEM | |
|---|---|---|---|---|---|---|---|---|---|---|
| Period of measurement (days of surveyings) | | | Feb 2008–May 2013 (42) | | Nov 2010–Dec 2013 (10) | | Nov 2007–Sept 2012 (6) | | Nov 2007–May 2013 (18) | |
| Days of surveyings | | | 1900 | | 916 | | 1829 | | 1992 | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Station | Height (m m.s.l.) | Days of submersion (days/yr) | Total lowering MEM (mm) | Mean lowering rate (mm/yr) | Total lowering MEM (mm) | Mean lowering rate (mm/yr) | Total lowering aTMEM (mm) | Mean lowering rate (mm/yr) | Total lowering dTMEM (mm) | Mean lowering rate (mm/yr) |
| A | 0.75 | 1 | 0.075 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.007 | 0.001 |
| B | 0.5 | 10 | 0.110 | 0.02 | 0.06 | 0.02 | 0.00 | 0.00 | 0.007 | 0.001 |
| C | 0.25 | 93 | 0.085 | 0.02 | 0.07 | 0.03 | 0.22 | 0.05 | 0.090 | 0.016 |
| D | 0 | 159 | 0.645 | 0.12 | 0.40 | 0.16 | 0.57 | 0.12 | 0.349 | 0.064 |
| E | −0.25 | 269 | 1.055 | 0.20 | 0.80 | 0.31 | 1.23 | 0.26 | 0.610 | 0.112 |
| F | −0.5 | 335 | 0.655 | 0.13 | 0.40 | 0.18 | 0.48 | 0.10 | 0.569 | 0.104 |
| G | −0.75 | 360 | 0.270 | 0.05 | 0.22 | 0.09 | \ | \ | \ | \ |

Differences in downwearing rates through time were measured. The MEM and dTMEM data were consistent, even if the MEM dataset was much less significant than the dTMEM data because of the low number of measurements taken for each station. Considering the MEM dataset, lowering rates between November 2008 and November 2010 were significantly lower than the period between November 2010 and December 2013 (Table 1, Fig. 2a,b). Regarding the dTMEM dataset, the increase of downwearing rates over time was similar to the increase highlighted by the MEM dataset (Fig. 2a). During the latter period (November 2010 to December 2013), in fact, the downwearing rates ranged between 0 mm/yr and 0.33 mm/yr (station E, MEM). Regarding the downwearing and the swelling of the limestone surface, they were usually similar along the whole slab (Fig. 2b). The downwearing and the raising usually occurred on all the stations during the same cycle of measurement (Fig. 2b).

Maximum total erosion was 1.23 mm (station E, aTMEM) over nearly 5 years (Table 1), while minimum total erosion was 0.007 mm (stations A and B, dTMEM). Most of the total lowering occurred during the period of November 2010 to May 2013 (Table 1). In particular, more than 65% of the total lowering occurred during the last period in correspondence of the lower stations (E to G).

The comparison of every cycle of measurements (Fig. 2a,b) highlights that the MEM and aTMEM data show higher lowering rates than the dTMEM data. The total lowering measured with MEM was 1.055 mm, while the total lowering measured with dTMEM was only 0.610 mm. The MEM and TMEM downwearing rates increased after 2010.

## 5. Discussion

The knowledge of erosion rates on vertical limestone surfaces in the intertidal zone represents a base for understanding and predicting long-term patterns of the evolution of coastal karstic features, including coastal notches. Direct measurements of erosion rates on vertical rock surfaces are very difficult to achieve, particularly with TMEM. The RSS method allows downwearing data to be collected from vertical rock surfaces simply by removing a limestone slab vertically set in the intertidal zone for very short periods of time, such as during a measurement cycle, as described by Furlani et al. (2010).

Downwearing rates and, as a consequence, the total surface changes vary according to the altitude above or below the mean sea level of the surveyed points. Regarding the ratio between the altitude of the studied stations and the days of submersion per year (Table 1), the uppermost station (A, Table 1) was nearly always emerged during the year, while the lowermost one (G, Table 1) was nearly always submerged. In general, the altitude lowered as submersion increased.

Most of the measurements (42) were collected using MEM because they could be achieved very quickly. Six measuring cycles were made using aTMEM, while 16 measuring cycles were made using dTMEM. Lower stations were often neglected because most of the surveyed points were covered by organisms (Table 1). Nearly 5 years of surveying highlighted that erosion rates are higher in correspondence to the stations located between 0 m and −0.5 m m.s.l. (Table 1). The maximum lowering rate observed at −0.25 m (station E) was 0.2 mm/yr (MEM) or 0.26 mm/yr (aTMEM). The maximum lowering rate using dTMEM was 0.12 mm/yr at −0.5 m m.s.l. (Table 1). Data collected with different instruments (MEM, aTMEM, and dTMEM) were globally consistent, since the order of magnitude at different heights above or below mean sea level was the same (Table 1, Fig. 3). Anyway, even if the MEM dataset is more regular and abundant, it is much less significant since our instrument is capable of collecting only one reading for each station.

Comparing data collected with the MEM during the periods of 2008 to 2010 (Table 1, Fig. 2b) and 2010 to 2012, lowering rates were higher during 2010 to 2012. From 2008 to 2010, downwearing rates slightly varied according to the altitude of the stations (Fig. 2a,b), while from 2010 to 2012, erosion rates significantly changed and stations located below the mean sea level lowered more quickly than the stations located above the mean sea level. Furlani et al. (2010) suggested that during the first year of measurements, the upper part of the slab slightly lowered because the upper stations were emerged for most of the time and the karstic solution and subaerial weathering processes prevailed. When active biological weathering started (that is, in 2010), the total amount of erosion increased, so that erosion rates therefore increased. It seems that 2 years after the slab positioning, biological colonization reached an equilibrium, and consequently, lowering rates started to follow the normal pattern of erosion. The erosion rates became similar to the rates measured by Torunski (1979) and Furlani et al. (2009). Stefanini et al. (1985) observed the same behaviour for limestones in a karst environment and suggested that the normal pattern of lowering starts after 1 to 2 years of exposure.

Regarding the future erosion trend along the vertical slab, it is probable that it will be consistent with the last 2 years of surveying, since the normal pattern of lowering started in November 2010 (Table 1), and the first time interval is not significant for the evaluation of long-term erosion rates since the slab was not in equilibrium

with the local environment. Stephenson et al. (2012) found that downwearing rates calculated over 2 years were representative of decadal scales. In our case, the mean lowering rates after 2010 ranged between 0.2 and 0.3 mm/yr below the mid-tide altitude, while they were lower above and below the mid-tide. Following the conclusions of Stephenson et al. (2012), these rates could be representative of the future erosion in the intertidal zone.

The erosion rates evaluated at the studied elevations highlighted a 'notch trend', with higher calculated rates occurring between 0 m and −0.5 m (Fig. 3). Bio-erosion played an important role in the downwearing of the limestone slab, even considering the significant increasing of erosion rates after the second half of 2010. Grazing and boring marks were observed mainly in the mid-tide zone. Also mixing-corrosion processes, due to the presence of the submarine karst springs, could have partly affected this process, as highlighted by Furlani et al. (2009), even if their contribution is very difficult to evaluate.

We can very cautiously use RRS as a technique to address MEM and TMEM data to explain geomorphological questions, as the genesis and development, or the presence or absence, of tidal notches. These data were consistent with observations provided by Pirazzoli (1980), Antonioli et al. (2007), Faivre and Fouache (2003) and Furlani et al. (2011a, 2011b), who reported the occurrence of a submerged notch in the Gulf of Trieste and the lack of a present-day notch, probably because limestone erosion rates are very low compared to the rates of local tectonic subsidence. Evelpidou et al. (2012) suggested that tidal notches are no longer forming in the present-day. The distribution of lowering rates in the intertidal zone suggests that notches up to 1 m in length could be carved in 3 to 4 kyrs.

Considering the fact that our results are mainly based on MEM data and the period of measurement was very short, our data could represent a starting dataset and the basis for modelling long-term tidal notch evolution in the Mediterranean Sea.

## 6. Conclusions

This paper summarises nearly 5 years of data collected on a vertical rock surface, obtained by positioning a limestone slab in the intertidal zone (using the RSS method) so as to allow measurements using different kinds of MEM and TMEM. Even if the setting was not completely natural, since the limestone slab was periodically removed from the operating position, it represents the longest and most complete dataset on vertical surfaces located in the intertidal zone. Dataset analysis suggests that the slab lowered at different rates according to the altitude above or below the mean sea level. Erosion rates were highest (0.32 mm/yr) mainly in the mid-lower intertidal zone and decreased downward and upward. The natural trend of erosion started in 2010 when, after 2 years of exposure, the slab was in equilibrium with the local environment. Even if most measures were collected using the MEM, these results are very important as a basis for future studies regarding tidal notch genesis and evolution, especially because the distribution of lowering rates in the intertidal zone is perfectly consistent with the shape of tidal notches and suggests that notches up to 1 m in length could develop in 3 to 4 kyrs at the present downwearing rates.

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