Geogr. Fis. Dinam. Quat.
29 (2006), 61-69, 6 figg., 2 tabb.

FRANCO CUCCHI (*), FABIO FORTI (**) & STEFANO FURLANI (*)

LOWERING RATES OF LIMESTONE ALONG THE WESTERN ISTRIAN SHORELINE AND THE GULF OF TRIESTE

ABSTRACT: CUCCHI F., FORTI F. & FURLANI S., *Lowering rates of limestone along the Western Istrian shoreline and the Gulf of Trieste*. (IT ISSN 1724-4757, 2006).

This paper discusses the data on the lowering of carbonate surfaces that have been taken from a series of measurement sites located along the shoreline of the Gulf of Trieste and of Western Istria, paying particular attention to the phenomena occurring in the intertidal zone. These lowering rates have also been compared with those of limestone outcropping in the Classical Karst area. The mean lowering rate of limestones along the North Eastern Upper Adriatic Sea is approximately 0.13 mm/yr, with significant changes depending on the site: in Trieste, the mean annual rate is 0.40 mm/yr; in the sites located along the Istrian shoreline, the mean annual rate is 0.09 mm/yr.

KEY WORDS: Coastal geomorphology, Limestone dissolution, Micro-erosion Meter, Classical Karst, Istria (Croatia).

RIASSUNTO: CUCCHI F., FORTI F. & FURLANI S., *Valori di erosione e di dissoluzione dei calcari delle coste dell'Istria occidentale e del golfo di Trieste*. (IT ISSN 1724-4757, 2006).

Si analizzano i dati di una serie di stazioni di misura della consumazione di superfici carbonatiche ubicate lungo le coste del Golfo di Trieste e dell'Istria occidentale, dedicando particolare attenzione a quanto avviene nella zona intertidale. I tassi di consumazione vengono inoltre confrontati con quelli dei calcari affioranti nel Carso classico. Il tasso di abbassamento medio dei calcari lungo le coste dell'Alto Adriatico nord-orientale è di circa 0.13 mm/a, con variazioni anche notevoli fra le stazioni: presso Trieste è stato misurato un tasso di consumazione medio annuo di 0.40 mm/a, mentre nelle stazioni lungo la costa istriana tale valore si abbassa a 0.09 mm/a.

TERMINI CHIAVE: Geomorfologia costiera, Dissoluzione carsica, Micro-erosion Meter, Carso Classico, Istria (Croazia).

(*) *Dipartimento di Scienze Geologiche, Ambientali e Marine, Università degli Studi di Trieste, via Weiss 2 - 34127 Trieste.*

(**) *Società Alpina delle Giulie, Club Alpino Italiano, via Donota 2 - 34121 Trieste.*

Our heartfelt thanks go to R. Odorico of the Marine Reserve of Miramare, Eduard Količ of the Brijuni National Park, E. Zahtila and R. Stelko of Natura Histrica, G. Ret - Major of D. Aurisina, G. Radivo, M. Rizzo and G. Floris of the Nettuno Study Society, F. Stravisi, A. Rossi and S. Erti for their precious help in the countryside and G. Burelli for the petrographic analysis of samples.

INTRODUCTION

Rocks located on the coast surface are exposed to weathering, which can be defined as the chemical alteration (dissolution, hydrolisys, etc.) and physical breakdown (due to water uptake, heating and cooling, freeze-thaw alternation, salt weathering, etc.) of rock material in response to environmental (in this case coastal) conditions (Trudgill, 1983). Wheathered materials are interested by erosion, which involves the removal and transport of weathering products from the original site to another location.

The most important process of limestone weathering is chemical dissolution, even though also other important factors contribute to the lowering of these surfaces. In the intertidal zone, due to the contact between water, air and limestone, besides chemical dissolution by freshwater (Higgins, 1980), biological weathering, in some cases the predominant one (Schneider, 1976; Schneider, 1977; Torunski, 1979), and mechanical weathering, caused by waves, by wetting and drying or by salt weathering, influence coastal weathering.

Even though erosion rates are low, it is possible to evaluate the lowering of the limestone surfaces using very accurate methods e.g., by repeated measurements of mass or volume loss (Gams, 1981; Forti & *alii*, 1975; Forti & Stefanini, 1981; Stefanini & *alii*, 1985) or by comparison of reliefs (Dahl, 1967).

To study intertidal lowering rates, the best method is surely the micro-erosion meter, (High & Hanna, 1970; Trudgill & *alii*, 1981; Forti, 1981; Cucchi & Forti, 1986; Cucchi & *alii*, 1987a; Cucchi & Forti, 1988; Cucchi & Forti, 1989; Cucchi & *alii*, 1995; Stephenson, 1997), which was used in particular to study rates and patterns of intertidal shore platforms (Viles & Trudgill, 1984; Spencer, 1985; Stephenson & Kirk, 1996), also in cases of short-term (diurnal) changes (Stephenson & *alii*, 2004).

Table 1 shows all the values measured by different authors on intertidal limestones.

TABLE 1 - Lowering rates from various Authors

Authors	Location	Mean annual rates (mm/yr)
Spencer (1985)	Grand Cayman Islands	0.29-3.67 (subtidal) 0.31-3.01 (intertidal) 0.09-1.77 (surf platform)
Stephenson & Kirk (1996)	Kaikoura Peninsula	1.10
Torunski (1979)	Gulf of Piran, Slovenija	0.07-1.114
Trudgill et al. (1976)	Aldabra Atoll, Indian Ocean	2.0-4.0
Trudgill et al. (1981)	Country Clare (Ireland)	0.145-0.383
Viles & Trudgill (1984)	Aldabra Atoll, Indian Ocean	1.27 (Ramp edge) 2.20 (Ramp foot)
Our Measurements	Northeastern Adriatic coast	0.00-0.34

To measure the erosion rates of the limestones that outcrop along the Northern Adriatic Sea, 3 MEM (micro-erosion meter) sites have been positioned along the Trieste Gulf shoreline and 2 sites along the Western Istrian shoreline, between the Rovinj and Brijuni Islands (Croatia), in collaboration with the Department of Geological, Environmental and Marine Sciences of the University of Trieste, the Coastal Reserve of Miramare, the Brijuni National Park and the «Nettuno» Study Society of Trieste. These are part of a network of measurement sites scattered throughout the North Eastern Karst area - extending from the Canin Mt. to the Istrian Peninsula. This network includes approximately 200 measurement sites and aims at assessing and quantifying the lowering rates of limestone surfaces exposed to weathering.

In particular, this paper presents the data collected in over one year of work in the 24 measurement stations located in the 5 coastal sites. The sites along the Trieste shoreline are positioned near the Villaggio del Pescatore (VP site), Duino (DM) and Miramare (MI). In Istria, a site is located near the Palud Lake shortly south of Rovinj (HRPA) and another one on the Brijuni Islands (HRPB). (fig. 1).

MATERIALS AND METHODS

Direct measurements of limestone lowering rates are collected via MEM. Trieste researchers started building MEMs in the 70's, following the experience gathered by High & Hanna (1970). Numerous papers illustrate the results obtained by Trieste researchers: these deal mainly with the Classical Karst - Italian sector (Forti, 1981; Cucchi & *alii*, 198b; Cucchi & Forti, 1988; Cucchi & *alii*, 1995), but sometimes they also consider other lithotypes (Cucchi & Forti, 1989) and other areas (Cucchi & *alii*, 1998).

Thanks to these instruments, measurements of the lowering rates of the exposed surface can be repeated at preset time intervals and always in exactly the same spot via a specially devised micrometer. The instruments are equipped with three specially-shaped supports, which are forced to adhere to three steel or titanium nails inserted into the rock, two of which have a semi-spherical head and one a flat head. A micrometer dial gauge firmly anchored to the supports, permits highly accurate measures of rock lowering.

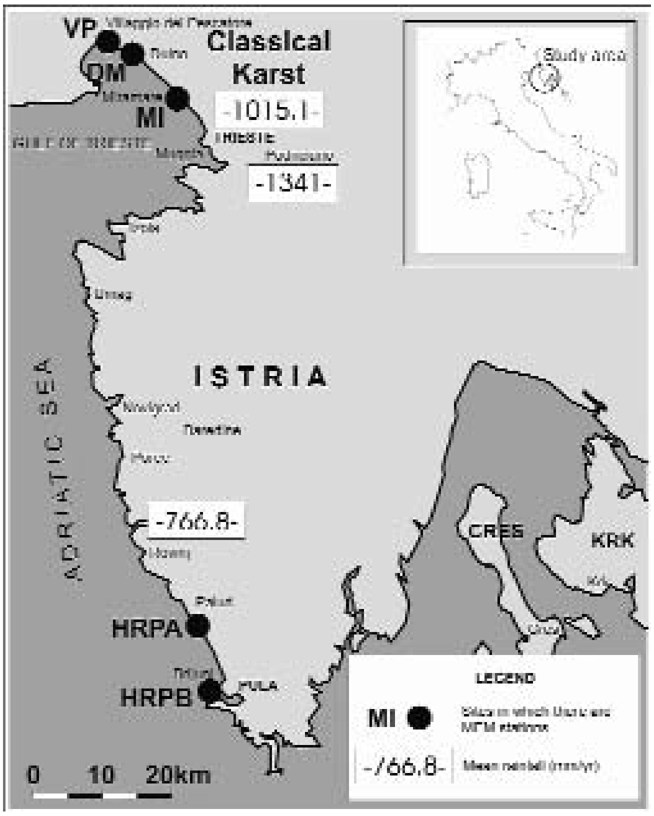

FIG. 1 - Location of the monitoring sites along the Classical Karst and the Western Istrian coast.

Following the example of Trudgill, who designed a new instrument (Trudgill & *alii*, 1981) called traversing-MEM - capable of taking different measurements in each single site, the Department of Geological, Environmental and Marine Sciences of the University of Trieste has equipped itself with a t-MEM built by Stefano Furlani. This t-MEM features a millesimal-resolution electronic dial gauge (fig. 2), thanks to which the data collected can be directly downloaded on a PC or on a palmtop (Stephenson, 1997).

The sites located on vertical walls, a rather frequent case in the coastal sector, are analysed by using the first type of MEM mentioned above, as the t-MEM can lead to incorrect readings. The altitudes have been measured via a Salmoiraghi Ertel automatic level and have been adjusted using the value of the mean sea level, measured via the tide gauge of Trieste at the moment of the survey.

FIG. 2 - The traversing micro-erosion meter (t-MEM) used by the authors.

CLIMATE

The coastal sector of the area is characterised by a Mediterranean climate, with hot and dry summers and mild winters. The inner Karst is instead characterised by a Continental type of climate, rather harsh and dry with significant thermal excursions. The climate that characterises the whole area varies therefore from the Mediterranean sub-continental to the Mediterranean continental climate, according to Righini & *alii*, 2002, with medium to very low precipitation in Spring, Autumn and Winter, long dry period during the Summer, which is partially arid, cold Winter and sultry Summer.

The average temperature along the coasts is approximately 14°C, whereas it reaches 16°C along the southern shoreline of the Istrian Peninsula. The coldest month is January, with temperatures lower than 6°C, whereas the hottest one is August, with 24°C.

Total average annual rainfall in the 1961-1990 period in the Trieste measurement site, located at the sea level, was 1015.1 mm/yr, whereas in the Padriciano site, located at 300 m above the sea level, the value reached 1341 mm/yr. In the Rovinj site, along the Istrian coast, average values of 766 mm/yr have been recorded.

The area is entirely exposed to winds coming from the third and the forth quadrant and is generally sheltered from the winds of the first quadrant (Bora).

The latter is particularly frequent (approximately 80 days/yr) and strong in Trieste. South-eastern winds may be particularly devastating (up to 17.5 m/s) and, though not frequent, can give rise to waves with lenght of 20 m and height of 3 m. The highest mean hourly speed for a SE wind in the Adriatic (1958-1987 [1]) was 27.3 m/s. SE winds do not enter directly the Gulf of Trieste, but only as reflected waves.

The Bora (ENE wind) lowers the sea level, whereas the winds of the third and forth quadrant raise it, thus leading to «high-water» phenomena. Unfortunately, there are no data available on the energy of the waves in this area.

The sea temperature ranges between 9° and 11° C, with peaks in August (24° C), even though near coastal springs it can remain constant throughout the year (about 13°C). Freezing is rare and affects only the most sheltered areas of bays. Salinity is higher in winter than during the summer and ranges between 31 and 38 psu. Highly remarkable differences in salinity levels are quite evident especially during floods, when the abundant river flow lowers values, mainly in the northern sector of the Gulf of Trieste.

Tides are mixed: they are usually semi-diurnal, with an average excursion of about 0.80 m in the Gulf of Trieste and with a lower amplitude (percentage values) along the southern Istrian shoreline (70% in Pula). Peculiar weather factors (the combined effect of southern winds, low pressure, etc.) can raise the level to approximately 2.0 m.

---

[1] http://www.istrianet.org/istria/meteorology/winds-sirocco.htm

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The eastern part of the Gulf of Trieste, from the Villaggio del Pescatore town to the Sistiana bay, is characterised by high, utterly pure and compact limestone plunging cliffs. Limestones date back to a period going from the Upper Cretaceous to the Eocene (Cucchi & *alii*, 1987), and its dip varies from strongly inclined to sub-vertical, sometimes tending to capsizing (Carulli & Cucchi, 1991).

In the VP site, sparitic bio-calcarenites outcrop (Alveoline and Nummulite limestones of the «Opicina Member», Palaeocene - Lower Eocene in age). The site is located on a short wall, in a zone that is quite sheltered from wave motion as it lies opposite a wide muddy tidal plain. It is completely protected by a large anthropic sand deposit. In the site there are 3 stations: VP1A and VP1B, located at +0,70 m a.m.s.l., VP3 positioned at –0.70 m. A fourth station, VP2, positioned at +0.20 m, was destroyed during a storm in 1990.

In the DM site (Duino is placed half way between the Pescatore Village and Sistiana), sparitic bio-calcarenites belonging to the Opicina Member are present. This site is characterized by the outcropping of well-fractured calcarenites. The site is particularly exposed to waves from the third quadrant, which, though not particularly frequent, may give rise to rather violent storms.

In the site there are 2 stations: DM5 and DM6, located at +1,60 m in the supratidal zone. Three stations (DM1, DM2, DM3 in the tab. 2), positioned in the mid 80's and located in the same zone, were completely destroyed after few years. During the exposure period (1982-1986), they recorded erosion rates between 0.19 and 0.03 mm/yr (Cucchi & Forti, 1989).

TABLE 2 - Lowering rates in the Classical Karst and in the North-eastern Istrian coast

Station	Altitude (m)	Years of monitoring	Days/yr of submersion	Lowering rate (mm/yr)	Notes
DM1	1.00	0.5	0	0.01	Destroyed
DM2	1.60	1.0	0	0.04	Destroyed
DM3	2.30	1.0	0	0.19	Destroyed
DM5	1.40	0.3	0	0.05	
DM6	1.65	0.3	0	0.02	
MI1A	0.25	1.4	62	0.27	
MI1B	0.15	1.4	93	0.33	
MI2A	0.20	1.1	78	0.34	
MI2B	0.20	1.1	70	0.26	
MI3	-0.26	0.6	263	2.12	
MI4A	0.20	0.7	78	0.26	
MI4B	0.20	0.7	70	0.22	
VP1A	0.70	16.1	1	0.01	
VP1B	0.70	11.1	1	0.01	
VP2	0.20	7.9	70	0.10	Destroyed
VP3	-0.50	0.7	335	0.09	
HRPA1A	0.05	0.8	131	0.04	
HRPA1A	0.05	0.8	131	0.06	
HRPB1A	0.20	1.0	78	0.06	
HRPB1B	0.20	1.0	78	0.05	
HRPB2A	0.20	0.6	70	0.04	
HRPB2B	0.20	0.6	78	0.06	
HRPB4A	0.20	0.4	78	0.14	
HRPB4B	0.20	0.4	70	0.26	

From the Bay of Sistiana to the Trieste harbour, the shoreline is interested by cliffs composed of interbedded sandstones and marlstones belonging to the Eocene Flysch, at whose basis small gravel-pebble beaches develop.

Near the Miramare Castle, located half way between Sistiana and Trieste on some olistoliths of Eocene limestone, the site MI was installed. Miramare olistoliths are composed of intensely tectonized fossiliferous sparitic limestones (almost breccias, anyway highly compact limestones) dating back to the Lower Eocene. The MI site is well sheltered because it is positioned in the harbour of the Miramare Castle.

In this site there are 7 stations. MI1A, MI1B, MI2A, MI2B are located at +0.25 m m.s.l., while MI4A, MI4B are just below the first ones (+0.20 m). MI3 is positioned in marly limestone outcropping in the proximity at –0.26 m. Sometimes this station is covered by cobbles.

South-western Istria can be regarded as a low limestone coast, intensely indented due to the penetration of the sea into karst valleys. The HRPA site features 2 stations, which are located at +0,20 m and at a short distance from the Palud pond, near Rovinj, on limestones with cyanobacterial mats with fenestrae and dissolution vugs.

On the Brijuni Island site, the stations are installed in two different areas: stations HRPB1A, HRPB1B and HRPB2A and HRPB2B lie close to the Uvala Verige and are placed at +0.20 m. Station HRPB4 lies at the same altitude on the Rt Ploče (Punta Lastre). They are all embedded into a well-sorted grainstone, Aptian in age, rich in Foraminifera and other bioskeletons. They are contemporary to those where, recently, dinosaur footprints have been found (Dalla Vecchia & *alii*, 2002).

Both the HRPA site and HRPB1 and HRPB2 stations are positioned in a relatively sheltered area, while the HRPB4 station is installed in a sector that is particularly exposed to winds of the second and third quadrant.

Stations whose altitude is higher than +0.60 m are immersed in water for less than 96 hours a year, whereas stations located at an altitude lower than –0.5 m are submerged for 8,040 hours out of the total 8,760 hours (365 days) of a year (fig. 5). TheVP1A, VP1B and VP2 stations, for example, located at +0.70 m, are submerged for approximately 24 hours a year.

RESULTS AND DISCUSSION

In 25 years, since 1979 to 2004, the measurement sites located on the Trieste Classical Karst have highlighted a mean erosion rate of 0.02 mm/yr, with a maximum value of 0.04 mm/yr on micritic limestone and a minimum value of 0.01 mm/yr on sparitic limestone (Cucchi & *alii*, 1995).

In the period from May 2003 to November 2004, the 11 stations of the 2 sites located in the intertidal zone of the Gulf of Trieste have instead recorded higher lowering values, reaching approximately 0.20 mm/yr, 10 times higher than the values pertaining to the inland limestones. Fairly quick is the lowering of the marly limestones outcropping near Miramare olistoliths (MI3). Here, lowering rates have reached 2.42 mm/yr and are hence at least ten times higher than those that characterize the neighbouring limestones (tab. 2).

Along the western Istrian coast, where there are 2 sites with 8 stations, lowering rates are on average 0.09 mm/yr. The values change depending on the stations: they are definitely low in the stations located in sheltered areas (HRPB1A, HRP1B and HRPB2A, HRPB2B), and remarkably higher in those positioned in more exposed zones (HRPB4) (tab. 2). The measurement site located in the inner Istrian Karst (positioned near Baredine) shows lowering values of approximately 0.02 mm/yr. (Forti, 2003).

Along our coasts, erosion rates appear to be higher in autumn (figs. 3, 4, 5) while on the Lias shale platforms along the Yorkshire coast in England (Robinson, 1977) and along the Slovenian coast (Torunski, 1979) rates increase during summer.

Values decrease at higher altitudes (supratidal zone) and at lower altitudes (subtidal zone), with maximum rates reaching +0.20 m (fig. 6). For this reason, a sharp and distinct zone can be identified, depending on the immersion time and on tide amplitude.

CONCLUSIONS

The preliminary analysis of the lowering of limestone surfaces due to the action exercised by atmospheric and marine agents has led us first of all to assess and quantify karst phenomena along the shoreline of the Classical Karst and of Western Istria. The data collected obviously highlight strong differences between the inner Karst and coastal karst areas: near the coast the erosion rate is ten times higher than the one recorded in the inland (0,2 mm/year to 0.02 mm/year).

The coastal sites that have been active for over a year are not numerous, but in the next few years it will be possible, thanks to t-MEM, to adopt a statistical approach in the study of coastal karst phenomena, such as the local marine notches (Antonioli & *alii*, 2004).

We have found maximum lowering rates just around the middle intertidal zone (+0.2 m). Lowering rates decrease both at higher altitudes (supratidal zone) and at lower altitudes (subtidal zone). Also Sunamura (1991), in a laboratory test, proved that the notch usually develops a little above the mean sea level.

Probably, the asymmetrical shape of the marine notches indicated by Antonioli & *alii* (2004) could be ascribed to the combined contribution of high intertidal lowering rates and the increasing local sea level (nowadays about 1.1 mm/yr in Trieste).

Low-altitude measurement stations appear to be more influenced by marine action than by rain action, and rates usually increase in the middle intertidal zone (fig. 6). Rainfall action is the predominant factor only when the sites are not submerged. It means that its influence depends on the altitude, without nonetheless excluding a thin «mix» of waters during the most violent rainy episodes.

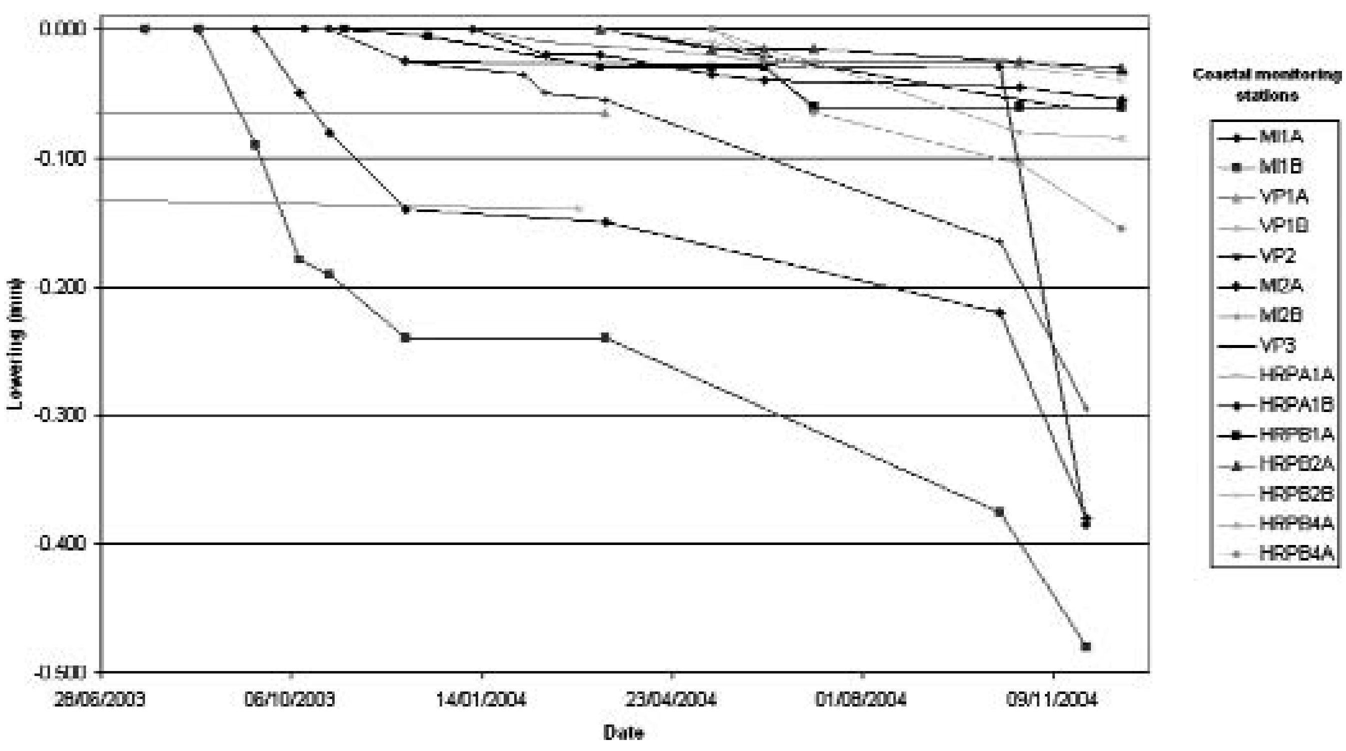

FIG. 3 - Lowering rates during 2003-2004 in all the stations except for MI3.

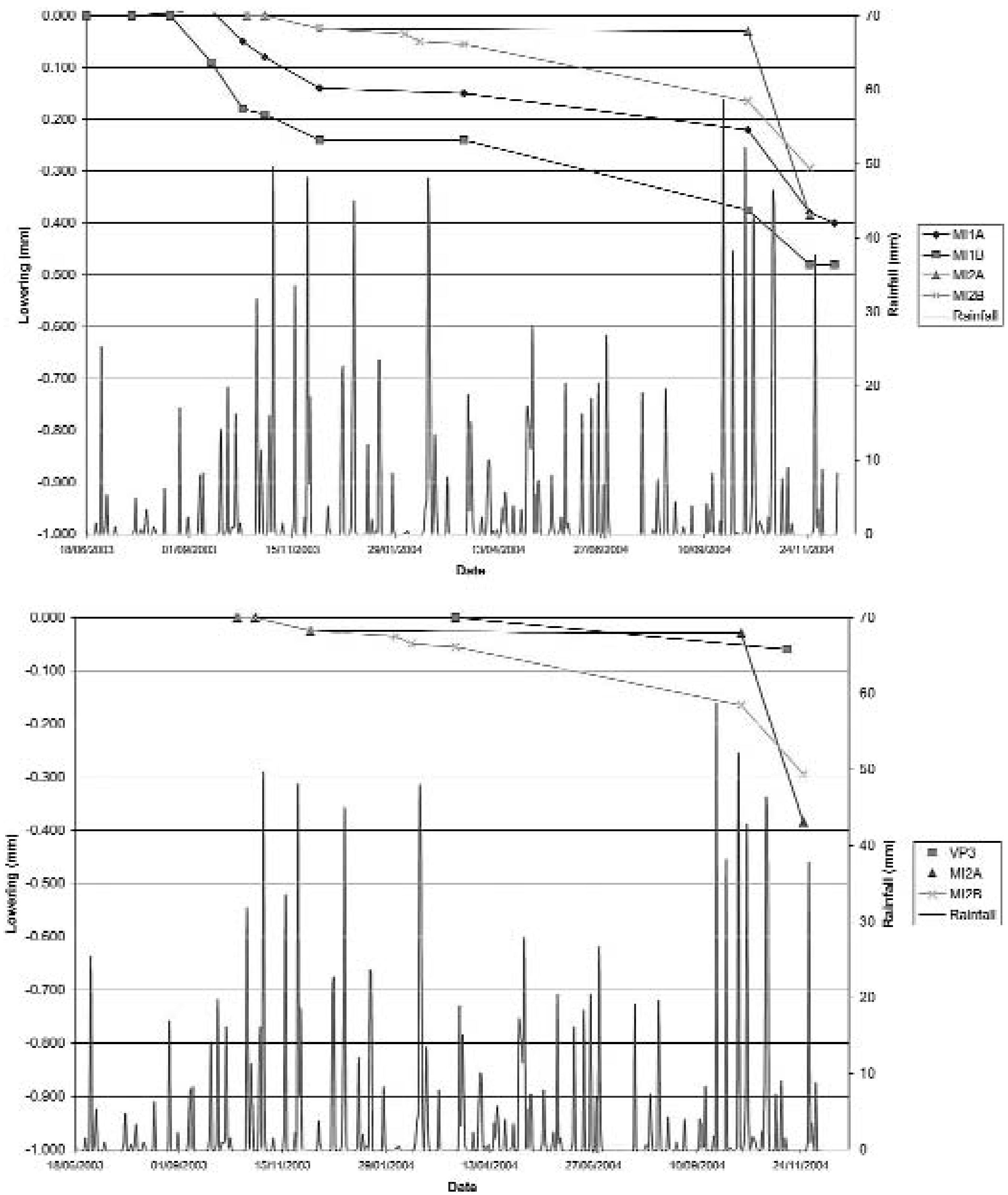

FIG. 4 - Lowering rates and rain during 2003-2004.

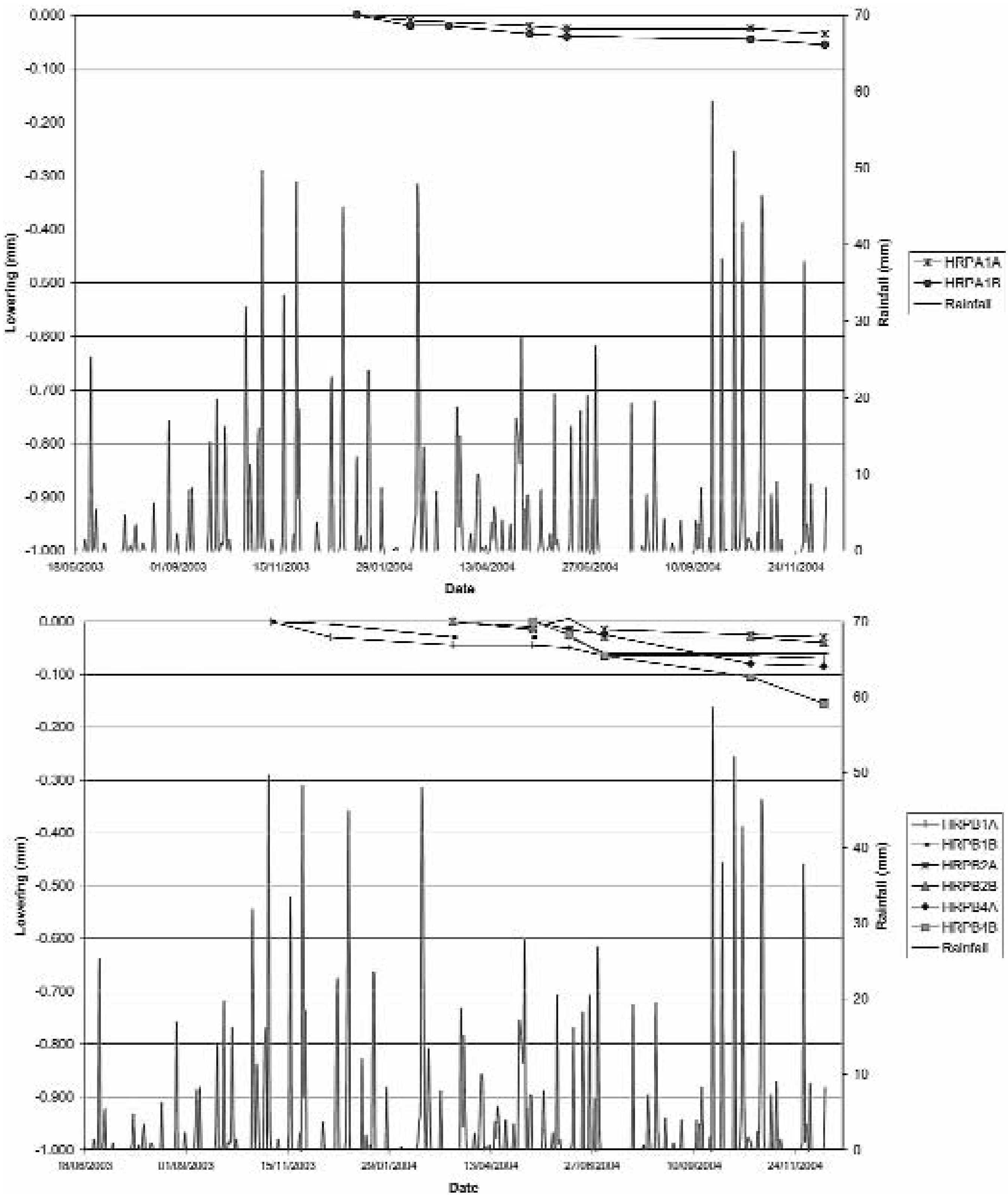

FIG. 5 - Lowering rates and rain during 2003-2004.

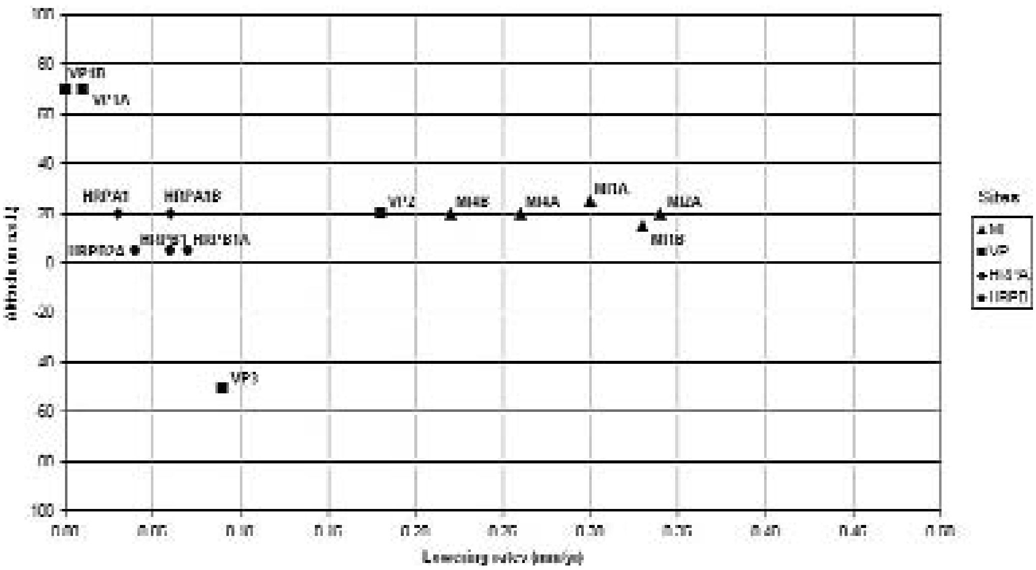

FIG. 6 - Relation between altitude (meter a.s.l.) and erosion rates for the stations located in the intertidal zone.

However, besides all these submillimetric values, it has to be borne in mind that 4 coastal measurement sites have been destroyed by the wave action in its extreme conditions. This means that the mechanical action of waves can significantly impact the morphological evolution of limestone coasts, particularly in the exposed sectors.

At the moment, it is difficult to quantify the contribution brought by each single factor - dissolution, erosion caused by wave motion, disgregation due to biological activity, etc. - because it is very difficult to isolate them. E.g. marine organisms (Torunski, 1979), and the presence of numerous submarine springs along the whole stretch going from Duino to Sistiana could give a remarkable contribution to the total amount of the lowering rate.

REFERENCES

ANTONIOLI F., CARULLI G.B., FURLANI S., AURIEMMA R. & MAROCCO M. (2004) - *The enigma of submerged marine notches in the Northern Adriatic Sea*. Quaternaria Nova, 8, 263-275.

CARULLI G.B. & CUCCHI F. (1991) - *Proposta di interpretazione strutturale del Carso triestino*. Atti Ticinensi di Scienze della Terra, 34, 161-166.

CUCCHI F. & FORTI F. (1986) - *Misure di dissoluzione di rocce carbonatiche: le ricerche a Trieste*. Atti e Memorie della Commissione Grotte «E. Boegan», 25, 97-102.

CUCCHI F., FORTI F. & FINOCCHIARO F. (1987a) - *Carbonate surface solution in the Classical Karst*. International Journal of Speleology, 16 (3-4, 1987), 125-138.

CUCCHI F., FORTI F., STEFANINI S. & ULCIGRAI F. (1987b) - *Mesures de dégradation de roches carbonatées et d'accroissement de stalagmites*. Spelunca Mémoires, 14, 87-90.

CUCCHI F. & FORTI F. (1988) - *La stazione di misura della dissoluzione superficiale a Borgo Grotta Gigante (Carso triestino, Italia)*. Atti e Memorie della Commissione Grotte «E. Boegan», 28, 87-93.

CUCCHI F. & FORTI F. (1989) - *Misure in situ di corrosione di rocce carbonatiche*. Atti XV Congresso Nazionale di Speleologia, Castellana Grotte - Bari, 1987, 623-634.

CUCCHI F., FORTI F. & MARINETTI E. (1995) - *Surface degradation of carbonate rocks in the Karst of Trieste (Classical Karst, Italy)*. In: Formos J.J. & Ginés A. (eds.), «Karren Landforms», Palma, 41-51.

CUCCHI F., FINOCCHIARO F. & FORTI P. (1998) - *Gypsum degradation in Italy with respect to climatic, textural and erosional condition*. Geografia Fisica e Dinamica Quaternaria, Supplemento IV - t. 3, 41-49.

DAHL R. (1967) - *Post glacial micro-weathering of bedrock surfaces in the Narvik district of Norway.* Geographiska Annaler, 49A, 155-166.

DALLA VECCHIA F.M., VLAHOVIČ I., POSOCCO L., TARLAO A. & TENTOR M. (2002) - *Late Barremian and Late Albian (Early Cretaceous) dinosaur track sites in the main Bioni/Brijuni island (SW Istria, Croatia)*. Natura Nascosta, 25, 1-36.

FORTI F. (1981) - *Metodologia per lo studio della dissoluzione con il sistema della misura con micrometro*. Atti e Memorie della Commissione Grotte «E. Boegan», 20, 75-82.

FORTI F. (2003) - *Stazione per la misura della consumazione carsica. Jama-Grotta Baredine Istria-Croazia.* Progressione, 49, 30-34.

FORTI F. & STEFANINI S. (1981) - *Modalità di una prova sperimentale eseguita per la definizione del grado di solubilità dei principali litotipi del Carso Triestino sotto l'azione degli agenti esterni.* Atti e Memorie della Commissione Grotte «E. Boegan», 20, (1980), 83-93.

FORTI F., STEFANINI S. & ULCIGRAI F. (1975) - *Relazioni tra solubilità e carsificabilità nelle rocce carbonatiche del Carso Triestino*. Atti e Memorie della Commissione Grotte «E. Boegan», 14 (1974), 19-49.

GAMS I. (1981) - *Comparative research of limestone solution by means of standard tablets.* Second preliminary report of the Commission of karst denudation (ISU). Proceedings of the Eight International congress of speleology, Bowling Green, July 18-24, A meeting of the International union of speleology. Bowling Green, National Speleological Society, 1, 2, 273-275.

HIGH C. & HANNA F.K. (1970) - *Method for the direct measurements of erosion on rock surfaces*. British Geomorphol. Research Group. Technical Bulletin, 5, 1-25.

ROBINSON L.A. (1977) - *Erosive processes on the shore platform of Northeast Yorkshire, England*. Marine Geology, 23, 339-361.

SCHNEIDER J. (1976) - *Biological and inorganic factors in the destruction of limestone coasts*. Contrains Sedimentology, 6, 1-112.

SCHNEIDER J. (1977) - *Carbonate construction and decomposition by epilithicmicro-organisms in salt and freshwater.* In: Fluget E. (ed.), «Fossil Algae, Recent Results and Developments», Springer Verlag., Heidelberg, 248-260.

SPENCER T. (1985) - *Weathering rates on a Caribean reef limestone: results and implications*. Marine Geology, 69, 195-201.

STEFANINI S., ULCIGRAI F., FORTI F. & CUCCHI F. (1985) - *Resultats experimentaux sur le degradation des principaux lithotypes du Karst de Trieste.* Actes Colloques 16° Congrès Nationale de Speleologie, Nancy-Metz, Spelunca, memoires, 14, 91-94.

STEPHENSON W.J. (1997) - *Improving the Traversing Micro-Erosion Meter*. Journal of Coastal Research, 13, 1, 236-241.

STEPHENSON W.J. & KIRK R.M. (1996) - *Measuring erosion rates using the micro-erosion meter: 20 years of data from shore platforms, Kaikoura, South Island, New Zealand*. Marine Geology, 131, 209-218.

SUNAMURA T. (1991) - *The elevation of shore platforms: a laboratory approach to the unsolved problem*. Journal of Geology, 99, 761-766.

TORUNSKI (1979) - *Biological Erosion and its Significance for the Morphogenesis of Limestone Coasts and for Nearshore Sedimentation (Northern Adriatic)*. Senckenbergiana Maritima, 11, 3/6, 193-265.

TRUDGILL S.T. (1976) - *The marine erosion of limestones on Aldabra Atoll, Indian Ocean*. Zeitscrift für Geomorphologie N.F., Suppl. Bd. 26, 164-200.

TRUDGILL S.T., HIGH C.J. & HANNA K.K. (1981) - *Improvements to the micro-erosion meter (MEM)*. British Geomorphological Research Group. Technical Bulletin, 29, 3-17.

TRUDGILL S.T. (1983) - *Weathering and Erosion. Sources and Methods in Geography*. Butterworths, 192.

VILE H.A. & TRUDGILL S.T. (1984) - *Long term remeaurements of micro.erosion meter rates, Aldabra Atoll, Indian Ocean*. Earth Surface Processes and Landforms, 9, 89-94.

(Ms. received 15 February 2005; accepted 30 September 2005)