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SHORT-TERM SURFACE CHANGES ON SANDSTONE ROCKS

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ABSTRACT

Short-term measurements, using a traversing micro erosion meter (t-MEM) on sandstone bare surfaces in two different locations within the Peninsula of Muggia, were surveyed. These stations have been monitored since 2004, first using a MEM, then a t-MEM. Median annual lowering rates in the studied stations, resulting from a monthly surveying, is 0.002 mm/yr (MUMV1) and 0.054 mm/yr (MUSB1). Daily surface changes, concerning the relative heights of 22 coordinates, were measured three times a day. The surveying shows that there are significant daily variations on sandstone surfaces. The maximum rise was –0.018 mm, while the maximum lowering was 0.009 mm. Maximum day variation is 0.027 mm. Observations made by various authors about the phenomenon of raising, particularly on shore platforms, is confirmed also for inland sandstones. The observed values suggest that the expansion and contraction of the bedrock could be related to wetting and drying processes. Comparison between meteorological and t-MEM data seems to indicate that during the night, bedrock surface rises due to water absorption, while during the day it lowers owing to the evaporation.

Key words: traversing-MEM, sandstones, surface rise, surface lowering, Muggia

VARIAZIONI MICROTOPOGRAFICHE A BREVE TERMINE DELLE ARENARIE

SINTESI

Vengono discusse misure MEM (micro-erosion meter) e t-MEM (traversing micro-erosion meter) raccolte tre volte al giorno, in due stazioni poste su arenarie, in due diverse località della penisola muggesana. Le stazioni (MUMV1 e MUSB1) sono monitorate mensilmente dal 2004, prima con il MEM ed in seguito con il t-MEM. Il tasso di consumazione media annua nelle stazioni indagate è di 0,002 mm/a (MUMV1) e 0,054 mm/a (MUSB1). Le variazioni superficiali dell'altezza relativa di 22 punti indagine per stazione sono state misurate tre volte al giorno. Lo studio mostra che ci sono significative variazioni giornaliere sulla superficie delle arenarie. Il massimo innalzamento misurato è stato di –0,018 mm, mentre l'abbassamento massimo di 0,009 mm, quindi una variazione massima di 0,027 mm. Le osservazioni fatte da vari autori sul fenomeno dell'innalzamento della superficie, in particolare sulle shore platforms, è confermato anche per le arenarie dell'entroterra. I valori osservati suggeriscono che l'espansione e la contrazione del substrato roccioso potrebbero essere collegati a processi di alterazione dovuti all'alternanza secco/umido tra la notte ed il giorno. La comparazione tra i dati meteorologici e t-MEM sembrano indicare che durante la notte la superficie dell'arenaria si alza a causa dell'assorbimento dell'umidità, mentre durante il giorno la superficie rilascia l'acqua attraverso l'evaporazione.

Parole chiave: traversing-MEM, arenarie, innalzamento della superficie, consumazione della superficie, Muggia

INTRODUCTION

Denudation is understood to be due to chemical and physical weathering and to erosion processes. The estimation of sandstone denudation rates is very important in order to elucidate both the role of sandstones in the geological context and to evaluate the durability of the rocks used as building materials. Many authors investigated weathering processes on sandstones: Takahashi *et al.* (1994) dealt with the reason for the variability and time-dependence in sandstone erosion rates. Paradise (1997) studied the differences between physical and chemical weathering due to lichens covering on sandstones, while Fitzner *et al.* (2003) and Turkington *et al.* (2003) surveyed the effects of weathering on sandstone monuments. Moreover, many researchers investigated the lowering rates of rocks all around the world, using different field or laboratory methods. The first ones did so by repeated measurements of mass or volume loss (Forti *et al.*, 1975; Gams, 1979; Forti & Stefanini, 1981; Stefanini *et al.*, 1985, Plan, 2005) and surface lowering rates via the micro-erosion meter (MEM), traversing micro-erosion meter (t-MEM) or Rock Erosion Meter (REM) (Forti, 1980; Cucchi & Forti, 1986, 1988, 1989; Cucchi *et al.*, 1987, 1996, 1998; Allred, 2004), while the second ones did so through laboratory investigations (Martinez & White, 1999) or through numerical models (Kaufmann & Braun, 2001). Additional surveys have provided the rates of down-cutting in the coastal sector, in particular on shore platforms (Trudgill, 1976; Kirk, 1977; Robinson, 1977; Torunski, 1979; Spencer, 1981; Trudgill *et al.*, 1981; Gill & Lang. 1983; Stephenson & Kirk, 1996; Stephenson, 1997). Among them, Kirk (1977) and Mottershead (1989) measured strange phenomena of surface rises, whereas recently, Stephenson *et al.* (2004), studying short-term changes on shore platforms, found hourly variations in surface height. They used the term "swelling" to describe surface rising. Gomez-Pujol *et al.* (2007) suggest avoiding using the term "swelling", because of its confusion with surfaces that remains elevated due to erosion processes and suggest to use the term "short-term surface change". Their results encouraged us to survey daily variations also in terrestrial setting.

This paper addresses these questions in the light of results from exposure trials conducted at the Muggia Peninsula (Fig. 1) since 2004 (Furlani & Cucchi, 2006). In order to compare the lowering rates of sandstones that outcrop on the Peninsula, we considered the MEM station located at the MUSB site. MUSB sites include 4 measuring laboratory-made stations, one on a micritic limestone from Borgo Grotta Gigante (Italian Karst), one on San Bartolomeo sandstone (studied herewith), one on Kastelir sandstone (studied herewith), and one on a chalk sample from Brighton (UK), collected by Dr. Robinson (University of Sussex). The aim of this paper is to investigate short-term lowering rates via MEM and t-MEM (Fig. 2) on two samples inland sandstones measured during the November 2006 – May 2007 period at the Muggia Peninsula.

MATERIAL AND METHODS

Study area

The Muggia Peninsula is located in the north-eastern part of the Adriatic Sea (Fig. 1). The area is characterized by interbedded sandstones and marlstones belonging to the formation of Eocene Flysch of Trieste. Marlstone layer spacing varies from millimetre to centimetre, while sandstone spacing is higher. Usually, sandstones are well-sorted, 0.1 mm in diameter. The light brown sandstone can be classified as a greywacke, characterized by a relatively high hardness, light brown color and poorly-sorted, angular grains of quartz, feldspar and small rock fragments set in a compact, clay-fine matrix and carbonatic cement. According to Vierthaler (1873) and Malaroda (1947), biotite is less abundant in Muggia, belonging to the "Muggia-Istrian" petrographic area, than in Trieste, belonging to the "Triestine" petrographic area, while density is higher in Muggia. On average, they are composed of quartz (43–53%) and flint (6–11%). The remaining part is composed of feldspar (18–26%) as plagioclase, mica (4–6%), carbonates (16–20% as cement or rock fragments, less abundant in Trieste than in Muggia) and other residual components (iron oxides, glauconite, tourmaline, garnet, zircon and rutil for less than 1–3%). They lack fossils apart from very rare rehandled Globigerinae and locally Medusas. The larger grains can be sand-to-gravel sized, and matrix materials generally constitute more than 15% of the rock by volume.

Geomechanical characteristics of sandstone of the Renice quarry highlight an apparent specific gravity of 2,720 kg m^{-3}, maximum water content of 0.95%, linear thermal expansion coefficient 0.0019 mm/ml/°C, while load strength varies from 945 kg m^{-2} to 908 kg m^{-2} (before and after freezing cycles). The tribometer test shows values of 2.7 mm (http://www.ts.camcom.it/marmi/italiano/marmi/masegno.htm).

The climate in the study area is Mediterranean continental (Righini *et al.*, 2001), characterized by equally distributed rainfall throughout the year, lightly rainier periods in the autumn (mean rainfall 290 mm) and less rainier in the summer (213 mm). Mean annual rainfall measured in the 1961–1990 period in Trieste (0 m a.s.l.) was 1,015 mm yr^{-1}, whereas in the inland Karst area (Padriciano site, 300 m a.s.l.) it was 1,341 mm yr^{-1} (Stravisi, 2003). The minimum mean value was recorded in February, while the daily peak is 105 mm in November. Storms are more frequent at the end of the summer and in the autumn. On average, there are 130 days per year when precipitations occur. In a year there are ap-

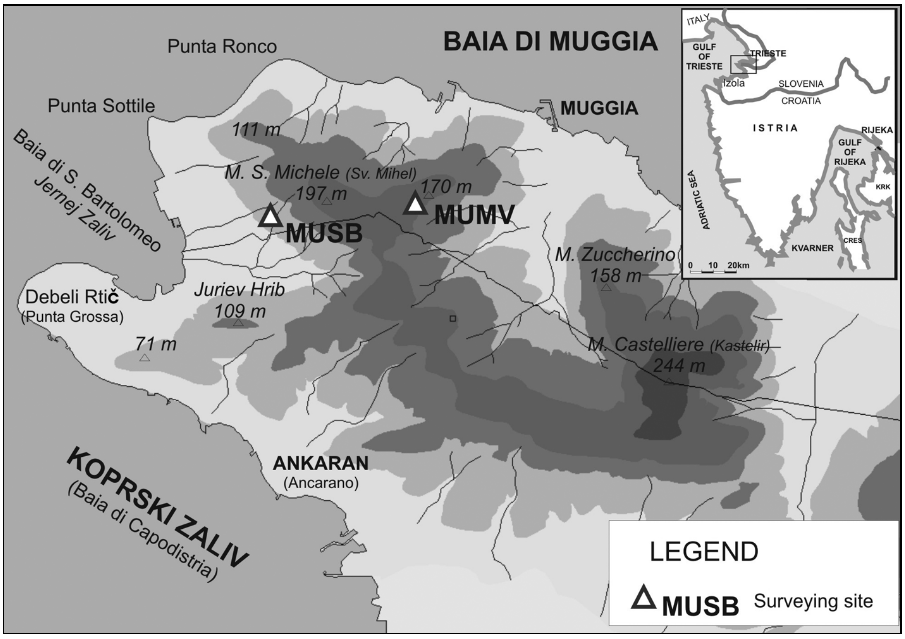

Fig. 1: Map of the Muggia Peninsula (Trieste, Italy) showing the location of the measuring stations (MUSB and MUMV).
Sl. 1: Zemljevid Miljskega polotoka (Trst, Italija) z lokacijami merilnih postaj (MUSB in MUMV).

proximately 31.5% of rainy days, 64.4% of sunny days, 3.0% of snowy days and 1.1% of days with hail (Tommasini, 1979). The hottest month is August (24°C), whereas the coldest one is January with temperatures lower than 6°C.

Sampling

Measurements performed at the selected sites located in the Muggia Peninsula are presented in this work. Each site contains numerous "measuring stations" and each measuring station is composed of three nails fixed on the rock. The MUSB site, located on a private property at Darsella di San Bartolomeo (Lazaret), includes 9 measuring stations. MUSB1 has been the first in operation at this site, as it was positioned on local sandstone in November 2005. MUSB2 surveys the lowering rates of a limestone collected in the Matajur area (Eastern Friuli). MUSB3 has been set to record the lowering rates of limestone collected in Borgo Grotta Gigante (Italian Karst). MUSB4 is placed on Aurisina limestone. The remaining MUSB5, MUSB6, MUSB7, MUSB8, MUSB9 include 5 different rock lithologies: a limestone from Borgo Grotta Gigante, a sandstone from San Bartolomeo, a sandstone from Kastelir Mt., a sandstone from a quarry in Muggia and one sample of chalk from Brighton. Moreover, long-term data collected in MUSB1 to MUMV1 have been compared (Fig. 3). MUMV1 is the oldest station in Muggia. The MUMV site is located in Muggia Vecchia Archaeological Park. The site includes one station positioned in June 2003 on local Eocene sandstone block.

Methods

Direct measurements of limestone lowering rates have been performed using a micro erosion meters (MEM), constructed by Trieste researchers since the 70's,

Fig. 2: The traversing micro erosion meter used in this study.
Sl. 2: Prečni mikro erozijski meter, uporabljen med to študijo.

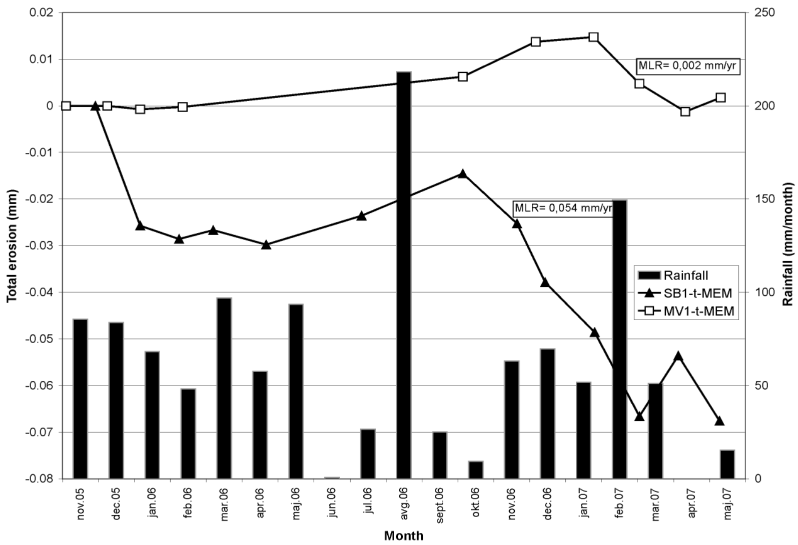

Fig. 3: Long-term lowering rates at MUSB1 and MUMV1.
Sl. 3: Dolgoročne vrednosti posedanja na postajah MUSB1 in MUMV1.

following the High & Hanna (1970) specifications and a traversing micro erosion meter (t-MEM) (Fig. 2). The instrument is equipped with three specially-shaped supports, which are forced to adhere to three bolts or titanium nails, two with semi-spherical and one with flat heads, inserted into the rock. The exact re-location on the fixed bolts is possible thanks to this configuration called Kelvin Clamp Principle. The engineering dial gauge is firmly fixed to the supports, thus allowing highly accurate analyses of rock lowering rates. The lowering rates of the surfaces can be repeated in exactly the same area at pre-set time intervals, using a specially designed engineering dial gauge.

Following the example of Trudgill's team, who constructed a new instrument (Trudgill *et al.*, 1981), the t-MEM, capable of collecting several measurements at each site, the Department of Geological, Environmental and Marine Sciences of the University of Trieste has assembled a t-MEM built by Stefano Furlani. The instrument is equipped with a millesimal-resolution electronic dial gauge, so that readings can be directly downloaded on a laptop computer (Stephenson, 1997). This configuration allows us to obtain a large data set, up to 238 measurements at a bolt site. Due to the large amount of sites, we decided to take 22 readings at each station. A calibration steel base was constructed to periodically check the instrument and to highlight differences in measurements. The electronic dial gauge has a resolution of 0.001 mm, while the error, confirmed by the builder (Mitutoyo), is ±0.003 mm. Probe erosion was estimated using two different methodologies: (1) by repeated readings on a test block, which revealed a probe erosion of 0.003 mm after 100 measures (research performed by the authors of this article) and (2) through observation via microscope of 34 touched rock samples (70 times) and untouched ones (research performed by Prof. Mauro Tretiach and Dr. Paola Crisafulli, Dept. of Geobotany, University of Trieste). In any case, readings below 0.010 mm must be considered with caution (Stephenson *et al.*, 2004).

Readings were taken at MUSB1 station during three periods, between 11 and 12 December 2006, between 26 and 27 February 2007, and between 6 and 7 May 2007. Temperature-related error, as pointed out by several researchers (Spate *et al.*, 1985; Stephenson *et al.*, 2004), was tested, but it turned out to be minimal due to the proximity of sites to the laboratory, in which the instrument is normally stored.

RESULTS AND DISCUSSION

The maximum duration of the measurement record at the stations located at the Muggia Peninsula was exactly 530 days, corresponding to the MUSB1 station, while the MUMV1 measuring site was surveyed for 493 days. The mean annual lowering rate in MUMV1 was 0.002 mm yr^{-1}, while in MUSB1 it was 0.054 mm yr^{-1} (Figs. 3, 4). In the Classical Karst, where measurements have been collected since 1979, lowering rates varied between 0.009 mm yr^{-1} on dolomites, 0.010–0.013 mm yr^{-1}on sparitic limestones and 0.038 mm yr^{-1} on micritic limestones (Cucchi *et al.*, 2006).

Statistics of daily variations for sandstone stations are presented in Table 1. It shows the results between readings collected each day. It contains the date of surveying, the number of surveyed points, the number of readings, the mean lowering/raising value, the median, the maximum and minimum surveyed value, the standard deviation and variance for daily variations. Negative values indicate a rising while positive values indicate lowering.

Tab. 1: Muggia descriptive statistics of changes (mm) between measurements.
Tab. 1: Statistika sprememb (mm) med merjenji na Muljskem polotoku.

Date	Surveyed points	Readings	Mean (mm)	Median (mm)	Max (mm)	Min (mm)	Range (mm)	SD	Variance
11-12/12/07	22	66	0.008	0.007	0.027	0.003	0.024	0.005	0.000
26-27/02/07	22	88	0.010	0.010	0.019	0.005	0.014	0.003	0.000
06-07/05/07	22	132	0.008	0.007	0.015	0.004	0.011	0.003	0.000

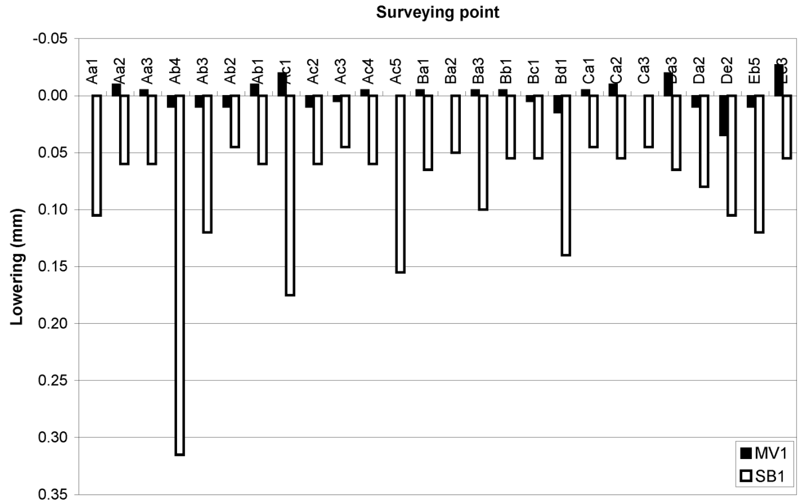

Fig. 4: Total annual surface change (mm) at MUSB1 and MV1 stations.
Fig. 4: Skupna letna sprememba (mm) na površju peščenjakov na postajah MUSB1 in MV1.

The global mean daily change is 0.009 mm (Fig. 5). On average, subsequent readings were not higher than 0.003 mm. Daily variations for each set of surveying points on each considered day do not show a normal trend and a large standard deviation affects measurements, so the most appropriate measure of central tendency is the median or the truncate average.

Daily measurements collected on sandstones in Muggia are shown in figure 6, together with humidity and temperature variations:

- three times (22:00, 9:00 and 13:00 h) on 11 and 12 December 2006. Measurements highlighted median diurnal variations of 0.007 mm, maximum surface change up to 0.027 mm, minimum 0.003 mm and a standard deviation of 0.005 mm.

- four times (22:00, 9:00, 13:00, 18:00 and 22:00) on 26 and 27 February 2007. Measurements highlighted median diurnal variations of 0.010 mm, maximum surface change up to 0,019 mm, minimum 0.005 mm and a standard deviation of 0.003 mm.

- four times (18:00, 22:00, 9:00, 13:00, 18:00, 22:00) on 6 and 7 May 2007. Measurements highlighted median diurnal variations of 0.008 mm, maximum surface change up to 0.015 mm, minimum 0.004 mm and a standard deviation of 0.003 mm.

The influence of a thin film of water on the rocky surface compared to a completely dry surface was tested in laboratory on the steel calibration block. A total amount of 144 measurements on dry surface and 88 measurements on wet surface was performed. Differences among them are lower than the estimated error of the instrument (0.004 mm).

From the analysis of t-MEM data, it was found out that there were significant variations in micro-topography during the day. It seems that these variations do not occur in a homogeneous pattern on the sandstones. Following previous cited works (Stephenson *et al.*, 2004; Gomez-Pujol *et al.*, 2007) we classified height variations of points as rising, falling and stable. Most of the points showed to fall during the day, probably due to the decrease in humidity and because of the solar heating, while there was a rising tendency during the night (the maximum rises were surveyed in the morning) as the humidity increased. Measurements collected on the steel calibration block showed that water did not influence directly the surface variations that considering the thickness of water would not change the surveyed values. This means that short-term variability in t-MEM values was no doubt due to a process occurring near the rock surface. Probably wetting and drying, as demonstrated by Mottershead (1989) and Stephenson *et al.* (2004), could be the most important factors on inland sandstones, too. On the subject, Blend & Rolls (1998) stated that wetting and drying is closely related to hydration shattering and could be related to

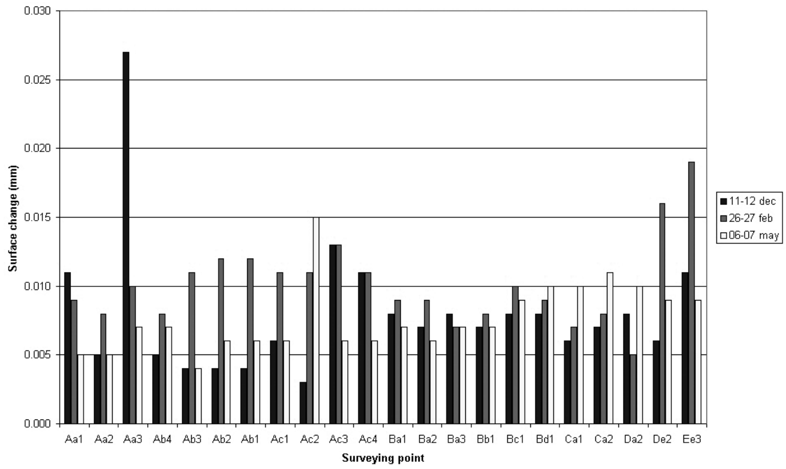

Fig. 5: Total surface variations (mm) recorded at the measuring stations during the three samplings performed in December 2006, February and May 2007.
Sl. 5: Skupne razlike (mm) na površju peščenjakov, izmerjene na postajah med tremi vzorčenji decembra 2006 ter februarja in maja 2007.

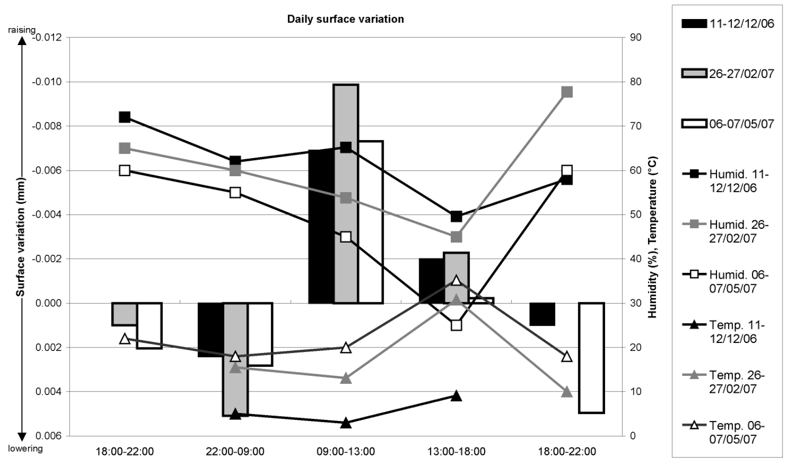

Fig. 6: Daily surface variations (mm) recorded at the measuring stations during the three samplings performed in December 2006, February and May 2007.
Sl. 6: Skupne dnevne razlike (mm) na površju peščenjakov, izmerjene na postajah med tremi vzorčenji decembra 2006 ter februarja in maja 2007.

unsatisfied electrostatic bonds in the surface minerals. The polar water molecules will be attracted by minerals in the small cracks of the surface, making a layer of adsorbed water. The addition of further water, as affirmed by the above mentioned authors, may cause a swelling-pressure which may in turn create strain. When water disappears, in this case by diurnal evaporation, the sides of the crack may be pulled together as attractive force. Cycles of wetting and drying could trigger diurnal expansion and contraction of the sandstone surface. Moreover, the surveyed sandstones are easily dependent on wetting and drying processes because of the presence of clay minerals, which help water absorption, some cleavage plains, which favour water penetration, and of high surface porosity.

CONCLUSIONS

Sandstone micro-erosion meter located in the Muggia Peninsula highlighted significant day-to-day variations. Inland sandstone surfaces seem to be a dynamic entity, showing both annual (from 0.002 to 0.107 mm yr^{-1}) and short-term (from -0.018 to 0.009 mm) lowering/raising rates. Our findings suggest that attention should be paid to the evaluation of t-MEM data, because they could cause an under- or over-estimation of the annual rates. Such variation had been previously reported in coastal environments and has now been surveyed on inland sandstone, too. The analysis of data on sandstones show that wetting and drying are the main processes concerning this phenomenon since raising/falling values are closely connected to daily variations in humidity, as already reported by Stephenson *et al.* (2004) on shore platforms. Further studies to elucidate the mechanisms of lowering, to investigate the internal properties of the sandstones and to compare sandstones changes to other rocks are needed.

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KRATKOROČNE SPREMEMBE NA POVRŠJU PEŠČENJAKOV

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POVZETEK

Avtorja pričujočega članka sta z uporabo prečnega mikro erozijskega metra (t-MEM) merila kratkoročne spremembe na golih površinah peščenjaka na dveh lokacijah na Miljskem polotoku (Muggia). Na teh postajah meritve potekajo že od leta 2004; najprej so bile opravljene z uporabo MEM, nato z uporabo t-MEM. Glede na mesečne meritve sta srednji letni vrednosti posedanja na preučevanih postajah 0,002 mm/leto (MUMV1) in 0,054 mm/leto (MUSB1). Dnevne spremembe na površju so bile merjene trikrat na dan z relativnimi višinami 22 koordinat. Meritve so pokazale, da na površju peščenjakov nastajajo pomembne dnevne razlike. Največji zabeleženi dvig je bil –0,018 mm, maksimalni ugrez 0,009 mm. Maksimalna dnevna razlika je znašala 0,027 mm. Opažanja, ki so jih o dviganju zabeležili različni avtorji predvsem na obrežnih terasah, so bila potrjena tudi za peščenjake v notranjosti. Zabeležene vrednosti nakazujejo, da je širjenje in krčenje površja substrata lahko povezano s procesoma močenja in sušenja. Primerjava med meteorološkimi podatki in podatki t-MEM kaže, da se površje substrata ponoči zaradi vsrkavanje vode dviga, medtem ko se ponoči zaradi izhlapevanja niža.

Ključne besede: prečni MEM, peščenjak, dviganje in nižanje površja substrata, Milje

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