SHORT TERM PEBBLE DISPLACEMENT ON A MIXED SAND AND GRAVEL BEACH ON THE ADRIATIC SEA (PORTONOVO, ITALY)

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Abstract

The transport of marked pebbles on a mixed sand and gravel beach has been addressed by means of tracers using radio frequency identification tracing technique, which proved to be efficient in terms of recovery rate also in the underwater environment. The aim of the research was to evaluate the displacement rates of marked pebbles at short time spans and under low energy wave conditions. The experiment was carried out at Portonovo beach, central Adriatic Sea (Italy), on 29-30 March 2012. Two recovery campaigns were carried out respectively 6 and 24 hours after the injection.. During the time frame of the experiment wave motion was minimum (wave height never exceeded 0.2 m). The results showed that pebbles of about 30 to 90 mm diameter did move significantly (more than 0.5 m) already 6 hours after the injection (17%). After 24 hours pebble significant displacements reached 39% and pebble loss increased to 7%. The large majority of tracers moved seaward, pointing out that coarse sediments move under low-energy conditions mainly because the beachface slope controls swash processes on coarse-clastic beaches. Backswash action contributes to generate not negligible rate of offshore pebble displacement also under low-energy conditions. In conclusion, the results of this research confirm that coarse sediment transport during short, fair-weather spans of time, is considerable and it is mostly directed downslope.

Key words: sediment transport, pebble, mixed sand and gravel beach, tracers, radio frequency identification, Adriatic Sea

1. Introduction

Morphodynamics processes on mixed sand and gravel beaches still lack an in-depth understanding even though in recent years they have been the focus of several scientific studies (e.g. Mason and Coates, 2001; Osborne, 2005; Ciavola and Castiglione, 2009). The transport of coarse gravel and pebbles on that kind of beaches is a topic that requires meticulous attention due to its vast influence on the system as a whole. On the other hand, sediment transport has been widely addressed in the scientific literature particularly for sandy beaches by means of different approaches, such as the study of sediment dispersal pathways, fluorescent tracers, composition analyses, biogenic debris were used to better define sediment transport along a given coast (Komar and Inman, 1970; McCave, 1978; Salomons and Mook, 1987; Ciavola et al., 1997; Ciavola et al., 1998; White, 1998; Benavente et al., 2005; Silva et al., 2007). Early studies focused on sandy beaches because it is easier to carry out fieldwork experiments on fine sediments rather than on coarse sediments (Buscombe and Masselink, 2006). Only recently sediment movement on coarse-clastic beaches has been extensively investigated (Allan et al., 2006; Curtiss et al., 2009; Miller et al., 2011; Bertoni et al., 2012). The scientific productivity on this type of environment increased mostly because of new technical solutions that solved many of the logistical problems, which were encountered during

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previous studies. For instance, the chance to track individual pebbles by means of the RFID (Radio Frequency Identification) technique provided a major boost towards the definition of coarse sediments displacement on coarse-clastic beaches (Allan et al., 2006; Bertoni et al., 2010). In addition, the use of gravel and pebble beaches as a form of coastal protection has progressively increased lately, because they are more resistant to wave action rather than sandy beaches (French, 2001; Masselink and Hughes, 2003). For that reason, the need to improve the knowledge about sediment transport processes in this environment has also improved. Coastal protection schemes involving the construction of artificial coarse-clastic beaches are expensive, and more insights about the morphodynamics might lead to the optimization of future defence projects and possibly to the reduction of costs.

The aim of this research was to define the transport pattern of marked pebbles on a low-energy, mixed sand and gravel beach during short, fair-weather spans of time (6 hours and 24 hours after the injection of the tracers). The results of this experiment pointed out that coarse sediment displacement is active and almost univocally directed downslope even when wave motion is low and tidal range is negligible.

2. Study Site

The study site is a natural beach located at Portonovo, a small village 10 km south of Ancona (Marche, Central Italy) in the central sector of the Adriatic Sea (Fig. 1). It is located within the Conero Regional Park, lying just at the foot of the Mount Conero. The Mount Conero is a headland representing the outer bulge of the Apennines chain toward the sea.

Figure 1. Geographical map of the study site

It consists of an asymmetrical anticline fold with north-eastern plunge (Calamita and Deiana, 1986). The headland is mainly constituted by carbonates and marls, which are the primary source that feeds the beach. The sediments that compose the beach are characterized by a wide range of grain-sizes that include sand, gravel, pebbles, and boulders. These heterogeneous dimensions were generated by the wave action that incessantly reworked the material collapsed from the north-eastern slope of Mount Conero in the prehistoric times, leading to the formation of the beach. For these reasons the study site represents a rarity in the usual context of sandy, gently-sloping beaches of the Adriatic Sea. The beach is about 500 m long with a maximum width of 50 m in the southernmost part and a minimum width of 15-20 m in the central sector up to the northern edge (Fig. 2a). Two small headlands bound the beach, preventing the sediments from leaving the system at least along the shore; no elements, neither natural nor artificial, are present offshore, thus sediments may be transported seawards. The bulk of the sediments constituting the beach body is naturally coming from the Mount Conero, but a small fraction was artificially introduced on the beach during a series of replenishments that took place in the last decade. This population is composed of carbonates of the same lithology of those already present on the beach: the sediments used as beach fill are granules and pebbles of about 4-to-100 mm diameter.

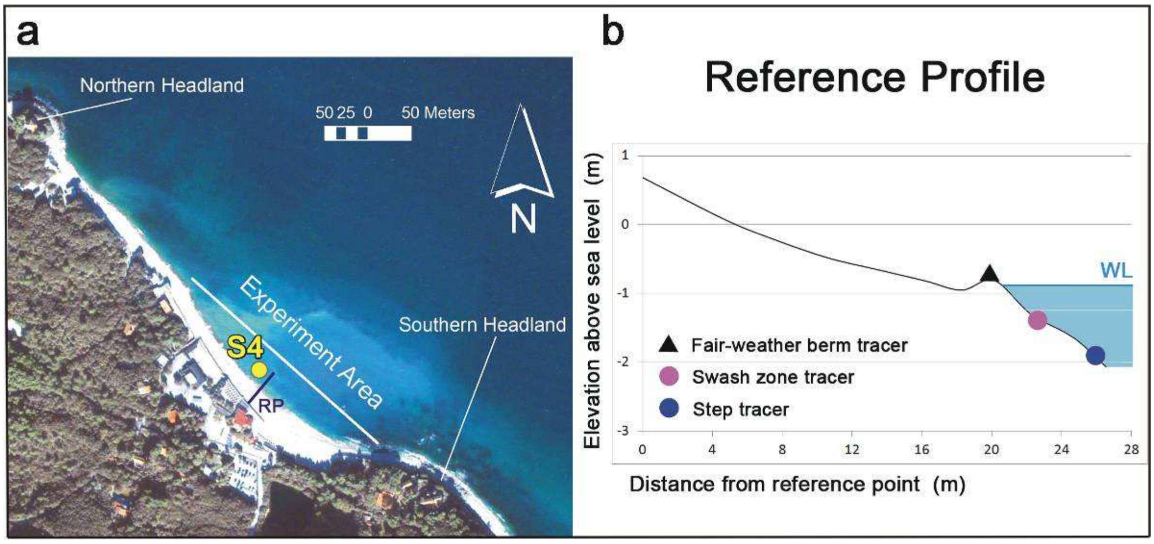

Figure 2. Setting up of the experiment: a) aerial view of Portonovo beach, where the wave gauge is indicated by the yellow dot; b) the profile that was taken as a reference during the experiment: the image shows where the tracers were injected. RP stands for Reference Profile

The sea bottom fronting Mount Conero belongs to the Adriatic continental shelf: it is mainly characterized by undulations and terraces, but its slope is gentle (0.01). As a matter of fact, the isobath -20 m represents the limit between an almost flat sea floor and a steeper slope seaward (Curzi, 1986). This sector of the Adriatic coast is characterized by a northward-trending littoral drift, which is the usual direction along the Marche coast (Regione Marche, 2005). Portonovo beach is microtidal, the maximum tidal range never exceeds 60 cm.

3. Methodology

The use of the RFID technology to track pebble movement was originally implemented for the subaerial portion of the beach (Allan et al., 2006; Curtiss et al., 2009), and it was later refined to work also in the underwater environment (Benelli et al., 2009). Being inexpensive and reliable, it assures high recovery rates with low maintenance costs. It basically consists of an antenna (the reader) transmitting a low-frequency, continuous radio signal, which is detected by a transponder (the tag) that is coupled to a pebble. The tag is unequivocally identified by a code that makes each pebble immediately traceable. The antenna reading range is about 40 cm; it decreases to 35 cm in the underwater environment. After collecting a sample of pebbles from the beach (with average medium axis between 30 and 90 mm), each tag was pasted to the particles inside a small hole, which was then filled with glue and resin to seal everything up. The tracers were injected on the beach on 29 March 2013 along cross-shore transects, placing a pebble on the fair-weather berm, one in the swash zone, and one on the step crest (Fig. 2b). Considering that no sediment tracing tests were ever performed at Portonovo beach, two marked pebbles were released on the same spots (on the swash zone and on the step crest) in order to check the consistency of the resulting displacement trends. The injection positions of each tracer were recorded by means of an RTK-DGPS (Trimble R6, instrument error of about 2 cm) as well as the positions where they were found back during the recovery campaigns. Tracer detection was carried out according to the Spatial Integration Method (Ciavola, 2004). The recovery campaigns were performed 6 and 24 hours after the injection, covering both the subaerial and underwater portion of the beaches. To avoid imprecision due to possible human errors while recording the recovery positions of the marked pebbles, it was considered as significant a displacement of at least 0.5 m. To better define the evolution of the beach profile, three topographic surveys were carried out during the time-frame of the experiment. The surveys were performed along a reference profile on both beaches during (i) tracer injection, (ii) 6 hours recovery, and (iii) 24 hours recovery. Wave conditions at Portonovo beach were recorded by an InterOcean S4 directional wave gauge that was deployed in the nearshore the day before the experiment (Fig. 3). The device measured wave and tide parameters and was operative during the entire time frame of the experiment. It recorded two time series per hour, each one resulting from 20 minutes bursts at 2 Hz. These characteristics were obtained using standard spectral analysis techniques.

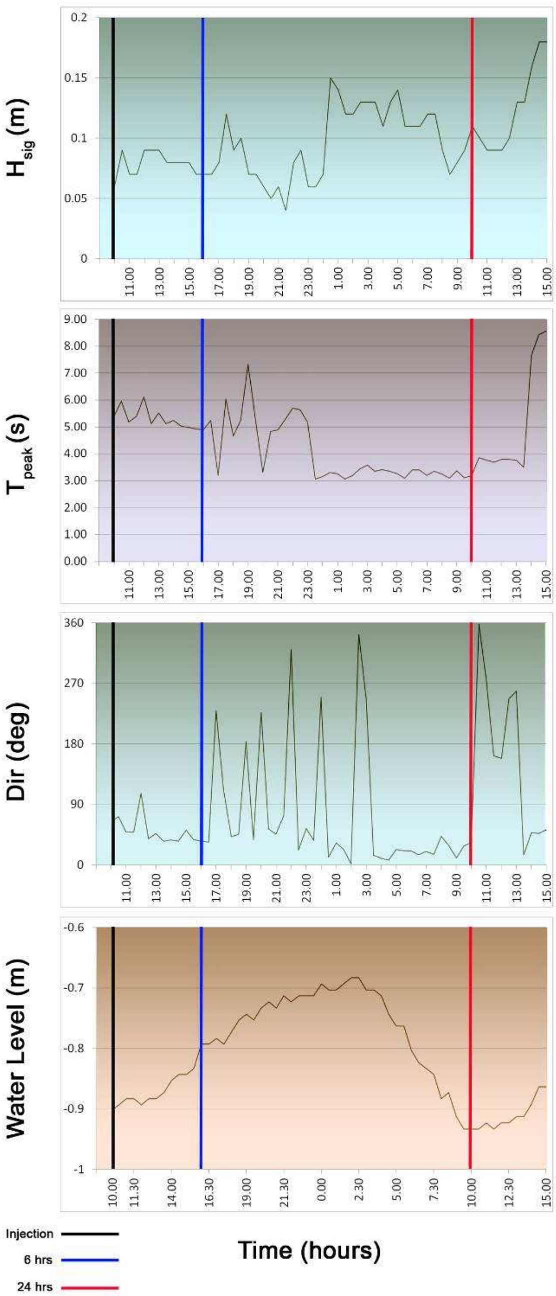

Figure 3. Wave and tide parameters recorded by the directional wave gauge during the experiment

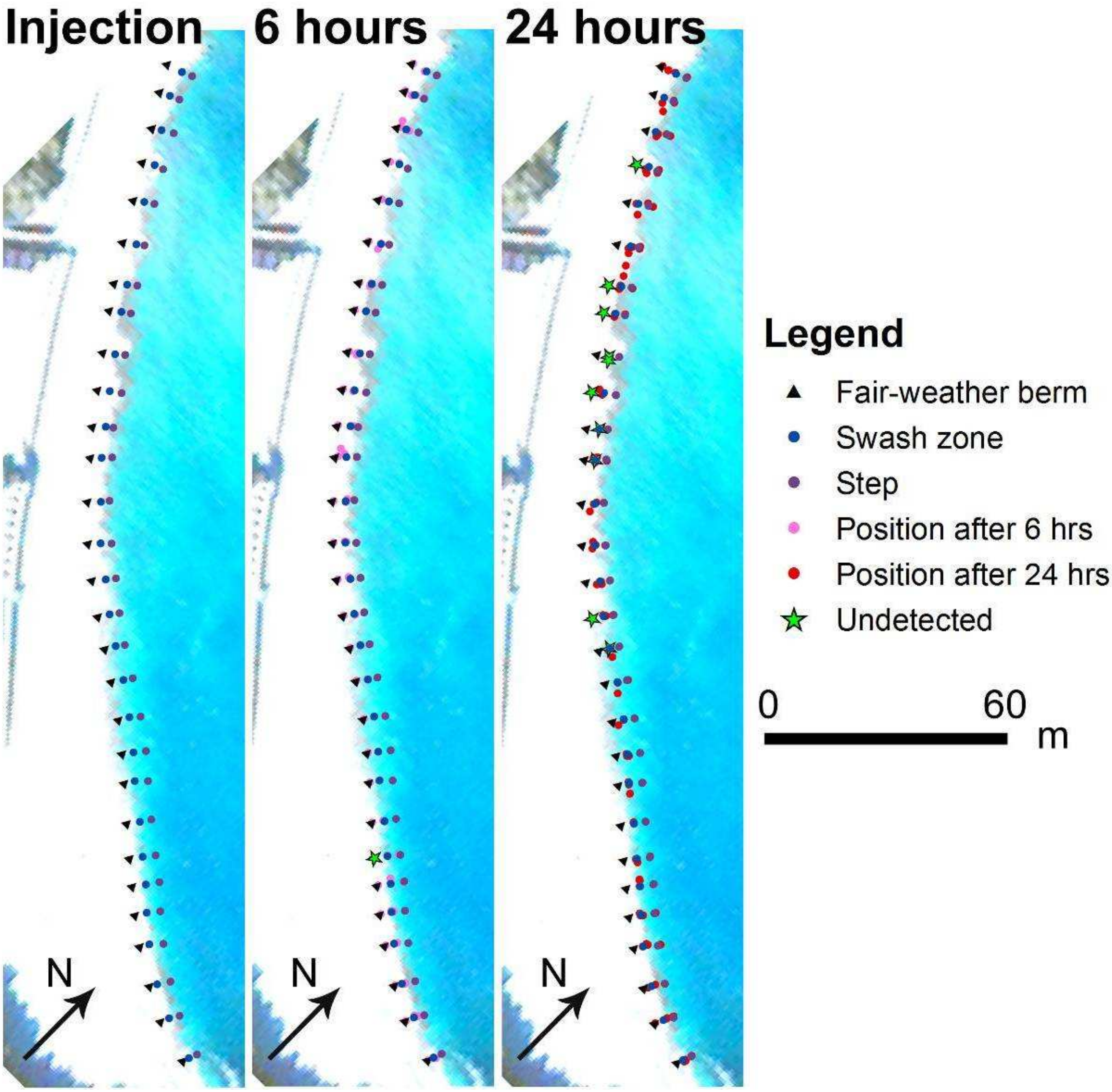

Figure 4. The positions of the pebbles at the moment of the injection and after 6 and 24 hours

4. Results

Wave motion at Portonovo beach was virtually absent during the time frame of the experiment. The significative wave height (H_s) never exceeded 0.2 m, being barely 0.1 m, on average. The maximum value that was recorded during the two days of testing was 0.18 m (Fig. 3). After the first survey (6 hours) only one tracer pebble was not detected, but after 24 hours from the injection the recovery rate decreased to 93% of the total (Tab. 1). Considering each injection position, 76% of the pebbles originally placed on the fair-weather berm showed displacement in excess of 0.5 m, which is the highest rate among the three injection locations after 24 hours. The swash zone resulted to be the area characterized by the highest transport rate after the first recovery campaign: 36% of the tracers released on the foreshore were quickly displaced, reaching over 0.5 m of transport just 6 hours after the injection. During the next 18 hours this figure did not increase as much, eventually settling at 50%.

Table 1. Recovery rate and percentage of pebbles that moved more than 0.5 m

Injection Position	**Total Recovery**		**Displacement over 0.5 m**	
	After 6 hours	**After 24 hours**	**After 6 hours**	**After 24 hours**
Fair-weather Berm	97%	83%	14%	76%
Swash Zone	100%	91%	36%	50%
Step	100%	100%	0%	10%
Total	**99%**	**93%**	**17%**	**39%**

The step crest is the area less affected by transport processes: any pebbles were neither lost during the entire experiment nor displaced over 0.5 m after 6 hours, and just 10% moved over 0.5 m, but only after 24 hours (Tab. 1). Regarding the direction of preferential sediment movement, the tracers were transported mainly downslope: 14 marked pebbles moved towards the beach step already 6 hours after the injection in constrast to 6 ones showing an onshore pattern. After 24 hours, the difference was sharper, since only 2 tracers were transported onshore and 33 offshore. Longshore displacement was minimum during the first 6 hours (4 pebbles), but it increased to 21 tracers after 24 hours. The transport tendencies are clearly visible on sediment dispersal maps as in Fig. 4.

5. Discussion

The preliminary results of the current experiment seem to suggest that swash processes are active on these type of coarse beaches even when wave motion is very low, determining considerable tracer movement mainly due to the destabilizing swash action on resting pebbles. In terms of movement direction, after the first recovery campaign (6 hours) the pebbles initially placed on the swash zone shifted prevalently downslope at Portonovo. These tracers were quickly entrained by uprush and backwash flux: the latter is responsible of the seaward displacement. The tracers basically needed just a small energy impulse to be moved and then they underwent a prevailing offshore transport. To notice that the pebbles used for marking at Portonovo have generally quite a good degree of sphericity and are from rounded to subrounded. Under the low energy conditions experienced during the time frame of the experiment, the slope of the beachface contributed to the downslope movement of the marked pebbles, which was triggered by the swash and then emphasized by gravity.

This is not in accordance with previous works carried out on coarse-clastic beaches, which reported a preferable onshore transport of coarse sediments (Deguchi et al., 1998; Mason and Coates, 2001; Buscombe and Masselink, 2006; Curoy, 2010). This different behavior can be explained considering that these studies were performed on sites characterized by high-energy beaches, where calm conditions are not usual. As a matter of fact, the results obtained at Portonovo agree with the work of Saini et al. (2012) on an estuarine coarse-clastic beach, which was exposed to wave energy conditions similar to those at Portonovo, at least in the short term. Once the tracers reached the step crest, they usually settled there because no other process was able to entrain them again under these low-energy sea-weather conditions. This notion is confirmed considering that swash zone pebbles that showed displacement over 0.5 m after the second recovery campaign (24 hours) were less than those that reached that figure after 6 hours. After 24 hours tracer transport rate increased also on the other injection sites, the step and the fair-weather berm. This trend was not caused by increased wave energy, rather by the swash action continuously reworking the foreshore. The rising tide did not play a major role, slightly adding up to that process in the way that enabled to reach higher elevations along the beach profile.

Field measurements show that at Portonovo the fair-weather berm was eroded and then formed again by swash action during the time frame of testing, which confirms the above-mentioned tendency (Fig. 5). On the contrary, after 24 hours the pebbles that were released on the berm showed higher transport rate rather than after 6 hours. They basically moved towards the step crest during the over-night demolition of the berm. The step crest resulted to be the area affected the least by any wave motion process: in terms of detection, at Portonovo every tracer injected on the step was found back even after 24 hours. Relative to the significant displacement, no step pebbles moved over 0.5 m after 6 hours, and only 10% did after 24 hours. Analyzing the trajectories of the pebbles that moved the most, a southward-trending shift can be reported. This is consistent with the wave direction during the time frame of the experiment (ENE), which determines the formation of a southward-trending drift. No differences in transport trend have been reported on the marked pebbles that were injected in duplicate at Portonovo, meaning that both tracers underwent similar displacement.

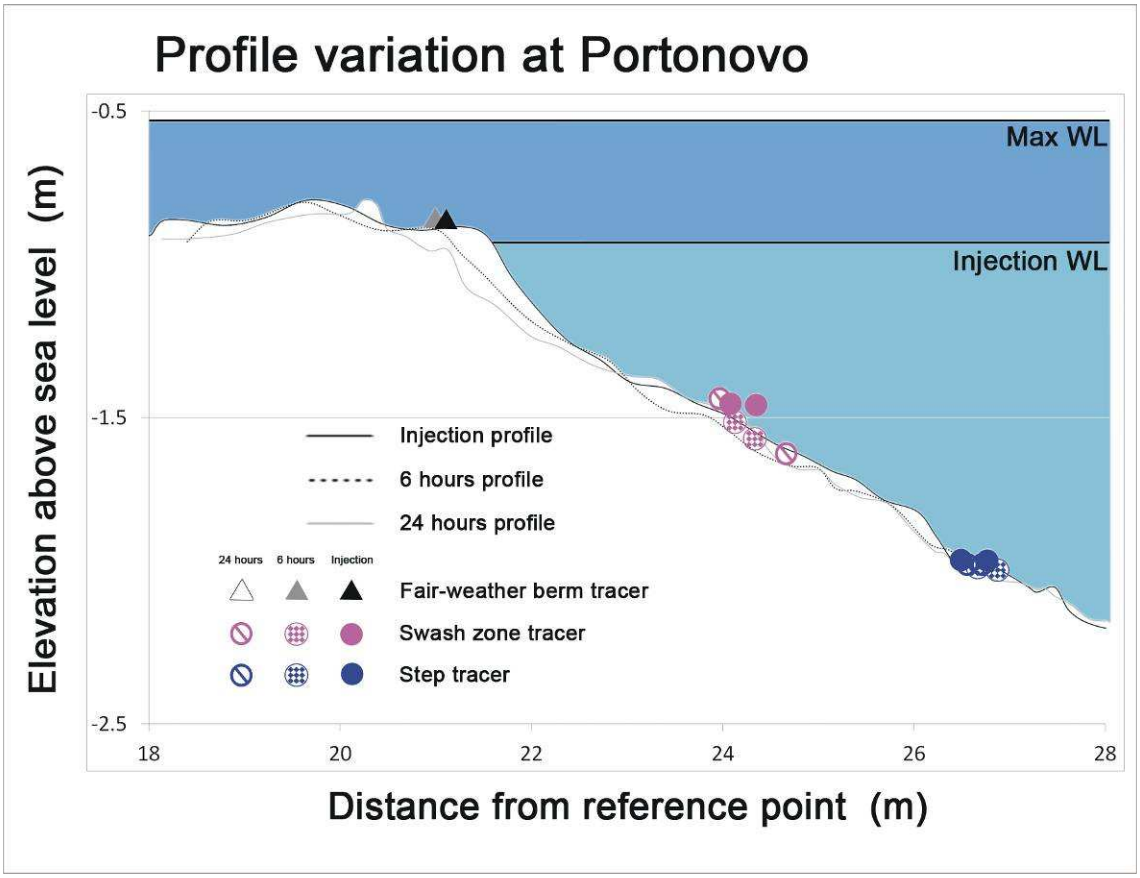

Figure 5. The evolution of the reference profile during the time frame of the experiment

It is important to discuss that pebble shape may be quite important in determining the transfer back from the step to the berm. Ciavola and Castiglione (2009), in an experiment using tracers at Porto Recanati beach, a few kilometers south of the site, observed that disk-shaped pebbles (major axis between 8 and 32 mm) were able to move upslope from the beach step to the berm crest under wave heights that reached more than 0.6 m. The particle's intermediate axis size and its shape were important in controlling the position of recovery above mean sea level. The closest the shape was to a disk, the higher the particle was found on the beach. At Portonovo the particles were slightly coarser (30-90 mm diameter) and more spherical. The choice of a the tracer was constrained by the size of the tag inserted. Thus, the use of different tracer size and/or shape may disclose different behavious.

6. Conclusions

The experiments performed on a mixed sand and gravel beach at Portonovo (Marche, Italy) confirmed that pebbles are expected to move in short periods even under very low energy conditions. Even though the wave action was low (wave height was never over 0.2 m), the swash processes were still able to determine significant transport rates, especially on the tracers that were injected in the swash zone. Pebble transport was prevalently directed downslope, because coarse sediments can hardly be moved back to the fair-weather berm under these conditions. This two-day-long experiment pointed out that under very low wave conditions gravel and pebbles just need a small quantity of energy to be destabilized. Once swash processes reach that threshold, the pebbles can be displaced away from the injection point. Future work will concentrate on assessing more in detail the role of pebble shape in determining particle position along the profile, using smaller tags and discriminating transport of different size classes.

Acknowledgements

The experiment would have not been completed without the cooperation of Prof. Javier Benavente of the University of Cadiz and Gino Brambilla, who were instrumental during the injection of the tracers and the recovery campaigns. We are also thankful to Dr. Mitchell Harley, who helped us out during the topographic surveys at Portonovo.

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