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Short term displacements of marked pebbles in the swash zone: Focus on particle shape and size

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ABSTRACT

In this paper, two short term experiments with tracers on a mixed beach are presented. The aim was to understand how the size and shape of pebbles can affect their transport under low energy conditions. Sediment transport was studied by means of RFID technology to univocally monitor every single marked pebble. A size subdivision of injected pebbles was conducted based on three classes ("Big" from −5.5 to −6.5 phi; "Medium", from −5 to −5.5 phi; and "Small", from −4.5 to −5 phi). Two recoveries were realised 6 and 24 h after the injection. During a single day, the wave motion was very low in the first experiment and low to moderate in the second (never exceeding 0.4 m). The results showed that discs are less dynamic than spheres but can cover greater distances. Regarding the sediment size, "Big" pebbles are less dynamic if compared to finer classes, and they move preferentially down the swash zone towards the step or do not move up-slope if already at the step. Very low and steady energy conditions facilitate cross-shore and offshore movement of pebbles, rather than a slight raise in wave height producing predominant longshore transport even with non-marginal displacements. Low to moderate energy conditions can also produce some trend displacement based on the pebble shape even though T-tests showed that shape was not statistically significant for pebble displacement. The displacements of "Medium" and "Small" sized pebbles show a statistical dissimilarity compared to the "Big" ones. To refine the velocity estimation necessary to initiate pebble movement, the threshold velocity formulas known up to now should involve the shape parameter, especially for the short term. Better knowledge of the relationship between the sediment's characteristics and dynamics is critical to forecast the durability of replenishment material and to establish the suitability of fill material relative to native beach material. Hence, a better understanding of the role of particle characteristics is necessary.

1. Introduction

Several hydrodynamic factors exert significant control on sediment transport for gravel and mixed sand-gravel beaches, and these factors are still poorly understood. A comprehensive review of these forces was made in the recent past (Kirk, 1980; Mason and Coates, 2001; Buscombe and Masselink, 2006), but finding clear correlations between sediment characteristics and hydrodynamic agents still represents a hard challenge, especially in the swash zone. Gravel is not only larger, but usually varies over several orders of magnitude greater than beach sands (Buscombe and Masselink, 2006) and this characteristic creates extremely evident texture variations on coarse clastic beach surfaces, which cyclically raises the interest of researchers. After the early papers written mainly around the 1970s and 1980s (Bluck, 1967; Carr, 1969, 1971; McLean and Kirk, 1969; Carr et al., 1970; McLean, 1970; Gleason and Hardcastle, 1973; Orford, 1975; Kirk, 1980; Caldwell, 1981; Williams and Caldwell, 1988; Isla, 1993; Isla and Bujalesky, 1993), a renewed interest in sediment transport based on different coarse particle characteristics formed during the first decade of this millennium (Buscombe and Masselink, 2006; Ciavola and Castiglione, 2009; Bluck, 2011; Bertoni et al., 2012a). Textural mosaics of different clast shapes and sizes are common and different cross-shore size-shape zonations and modes of transport were demonstrated by many authors (Bluck, 1967, 2011; Orford, 1975; Williams and Caldwell, 1988; Isla, 1993; Ciavola and Castiglione, 2009; Hayes et al., 2010), although the relative importance of size and shape in sorting sediment is yet to be resolved (Buscombe and Masselink, 2006). According to Kirk (1980), the most complex aspect of mixed beaches relates to sediment characteristics. Orford (1975) noted that the roles of size and shape cannot be easily separated; using both factors is therefore well-advised to establish the degree of pebble zonation on a beach before carrying out sedimentological characterisation. Williams and Caldwell (1988) proposed a model wherein the influence of particle size is more important on the sorting of sediments when energy conditions are high, while particle shape predominates when energy conditions are low and cross-shore sediment transport prevails. Because most of the cited papers relate to meso- or macro-tidal beaches, except for

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Ciavola and Castiglione (2009), who provided insights on a micro-tidal beach, the aim of this work is to develop further ideas on this type of beach attempting to discriminate whether shape and size affect differentially pebble displacements in the swash zone under low-energy conditions. Furthermore, thanks to the RFID technology that enables the unambiguous identification of pebbles (Allan et al., 2006; Bertoni et al., 2010), it is possible to describe the movement of each individual particle according to its characteristics such as shape and size. This tracing technique, according to Van Wellen et al. (2000), is currently best suitable to obtain short-term transport rates on coarse-grained beaches.

2. Regional setting

The study area is a mixed sand–gravel beach located in Portonovo on the northern edge of the Conero Headland in the central sector of the Adriatic Sea (Fig. 1). The beach is located on the eastern side of the village, it is approximately 500 m long and 20 to 60 m wide and is bounded by two boulder seawalls protecting historical buildings. The southern portion of the beach is wider and slightly embayed, whereas the northern part is narrower and straight. The beach was formed by a prehistoric landslide from the Conero Headland (Coccioni et al., 1997). In this sector of the Adriatic Sea, the littoral drift is directed northwards (Regione Marche, 2005), but this has no effect on Portonovo beach sediment transport because of its longshore boundaries. Cliff erosion is the only sediment source as there is no river input; the natural sediments consist of marls and limestones. The sediments vary from medium sand to cobble with a prevalent gravel fraction mainly formed by pebbles. The beach face typically slopes 0.2, whereas the seabed seaward of the step is approximately 0.01. The beach looks extremely heterogeneous regarding the surface sediment grain size: sand and scattered gravel accumulations cover the backshore whereas the gravel fraction usually occupies the swash zone, with granules and fine pebbles normally found on the berm and in the swash zone while cobbles and boulders are usually found on the step. According to the Jennings and Shulmeister (2002) classification of gravel beaches, Portonovo is a mixed sand and gravel beach (MSG), which is characterised by a complete intermixing of sandy and gravelly sediments (Fig. 2).

In 2010, a replenishment made of alluvial material compatible with the original sediment was carried out by local authorities: pebbles and cobbles (4–100 mm in diameter) of limestone were used to contain beach erosion. The total amount of fill material deployed on Portonovo beaches between 2006 and 2011 was approximately 18,500 m^3: most of it was unloaded on the western side of the village (Fig. 1, personal communication by officers of the Regione Marche). The exact location and quantity of fill material released in the eastern side of the town are unknown. The average tidal range at spring tide is 40 cm in the Ancona area (Colantoni et al., 2003). The dominant winds come from the NE and SE, which correspond to the directions of the main storms. The typical wave heights are between 0.25 and 2 m, with 20% of waves coming from SE and 15% from NE (data recorded by the Ancona offshore wave buoy of ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale, in the period 1999–2006, Fig. 3).

3. Materials and methods

Two tracer experiments were set up at the Portonovo beach. The first one was carried out in March 2012, and the second took place in April 2013. In both cases, the pebble displacement was investigated by

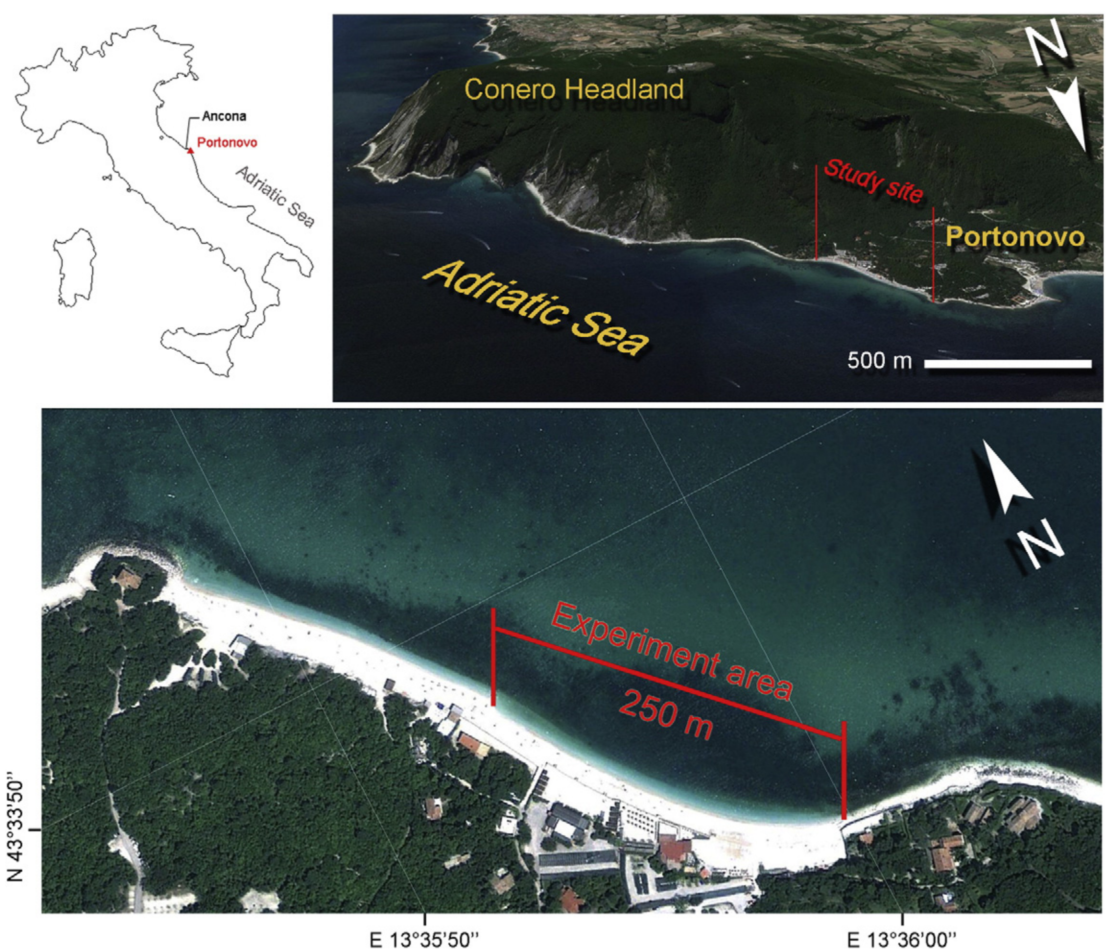

Fig. 1. Study site.