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Neoichnology of a barrier-island system: The Mula di Muggia (Grado lagoon, Italy)

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ABSTRACT

Barrier-islands are common landforms and biodiverse habitats, yet they received scarce neoichnological attention. This gap is tackled by studying the Mula di Muggia barrier-island system (Grado lagoon, Italy), focusing on morphology, ecology and ethology of individual traces. The following incipient ichnotaxa are identified: *Archaeonassa*, *Arenicolites*, *Bergaueria*, 'diverging shafts', *Helminthoidichnites*, *Lockeia*, *Macanopsis*, *Monocraterion*, *Nereites*, *Parmaichnus*, *Polykladichnus*, *Skolithos*, *Thalassinoides* and 'squat burrows'. Vertebrate (*Avipeda-/Ardeipeda*-like, *Canipeda*) and invertebrate tracks ('parallel furrows') are also described.

For each ichnotaxon, tracemaker and behavior are discussed, together with their position with respect to sediment barriers. Results suggest that sediment barriers impose a sharp contrast in terms of ichnological composition. Back-barrier is dominated by branched burrows (i.e. *Thalassinoides*, *Parmaichnus*), while the fore-barrier presents vertical and U-shaped burrows (*Arenicolites*, *Skolithos*). The environmental conditions of the back-barrier show that low-oxygen substrates favor intense bioturbation, provided that the water column is sufficiently oxygenated.

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1. Introduction

Barrier-islands are elongate accumulations of unconsolidated sediment that separate the open sea from a landward restricted basin (Schwartz, 2005; Nichols, 2009). At present day, they are important coastal landforms, lining the 10% of the world's shoreline length (Stutz and Pilkey, 2011). Barrier-island systems are also well-represented in the rock record, being documented from the Mesoproterozoic onwards (Köykkä and Lamminen, 2011).

This conspicuous record is not the only reason of importance. In fact, barrier-islands are normally delimiting coastal lagoons, which play a major ecological role. In fact, they commonly provide a collection of habitat types for many species, housing high biodiversity levels and considerable biomass (Pérez-Ruzafa et al., 2011). Historically, barrier-island ecosystems supported numerous human communities, which often posed a threat to these fragile environments (Pérez-Ruzafa et al., 2011). At this regard, barrier-islands are also very sensitive to sea-level rise and storm patterns, thus providing clues to process changes through time (Mallinson et al., 2010).

Despite their inferred importance, barrier-island neoichnology is relatively understudied. In fact, in contrast to the large number of ecological and sedimentological studies, comparatively few barrier-island systems received neoichnological attention: the Wadden Sea (e.g. Cadée and Goldring, 2007; Hertweck et al., 2007), the Georgia Coast (e.g. Howard and Frey, 1985; Martin, 2013) and the New Brunswick Coast (Hauck et al., 2009).

There is therefore a need for neoichnological records of barrier-island systems, in terms of either autecology or synecology of bioturbation. This goes in parallel with another *tenet* of neoichnology, the need of studying tidal depositional systems, which received less ichnological study than wave-dominated environments (Buatois and Mángano, 2011).

The Grado-Marano lagoon (Italy) satisfies both requirements, presenting a vast complex of barrier-islands within a low-energy, tide-influenced regime. Within the Grado lagoon, the area of the Mula di Muggia provides optimal study conditions, given its particularly integer environment. More specifically, the goal of this study is to provide information on morphology, ecology and ethology of individual traces. Knowledge of these aspects is essential for the understanding of the ichnological system as a whole, which will be discussed quantitatively in Baucon and Felletti (2013–this issue).

2. Study area

The Grado-Marano lagoon, located along the Adriatic coast in Northern Italy, is composed of two communicating shallow basins known as the Grado and Marano lagoons. The lagoonal complex started to develop during the transgression that followed the end of the last glacial maximum. The Marano basin is older (5000 years BP), while the Grado lagoon formed in post-Roman times as the result of the diversion of the Isonzo River (Gatto and Marocco, 1992; Triches et al., 2011).

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At present day, the Grado-Marano lagoon extends between the Isonzo and Tagliamento rivers, stretching out for about 160 km^2. The lagoon is connected to the sea through inlets which subdivide barrier islands into six segments (Blasutto et al., 2005; Triches et al., 2011). The tidal magnitude is unusual for the Mediterranean Sea, with semidiurnal mean and spring tidal ranges of 65 and 105 cm respectively (Sconfietti et al., 2003; Covelli et al., 2008). Climate is temperate, influenced by ENE (Bora) and SE (Scirocco) winds (Fontolan et al., 2007).

Although the Grado-Marano system has been subject to significant anthropogenic pressure over the past centuries (Covelli et al., 2008), it remains one of the more pristine wetlands in the Northern Adriatic and Mediterranean Sea as well. In fact the lagoon of Grado and Marano is an important ecological system, both for the habitats of numerous vegetal and animal species (Sconfietti et al., 2003; Ferrarin et al., 2010; Barbone et al., 2011). In particular, the area of the Mula di Muggia Bank (Fig. 1) is recognized for its outstanding biodiversity, for which reason it is receiving environmental protection (i.e. Ramsar Convention, EU Natura 2000 Network; Barbone et al., 2011). Here, a shallow lagoon is fronted by sediment barriers (Fig. 2), which are significantly moderating the effects of waves and currents (Fig. 1). Two geomorphological domains are distinguished on the basis of position with respect to the sediment barriers:

1. the back-barrier (Fig. 3A) is dominated by muddy sand, commonly covered by dense seaweed meadows (Video 1). Laminated and filamentous microbial mats develop on intertidal flats.
2. the fore-barrier (Fig. 3B) present higher-energy conditions and rippled sand. Shell debris is locally abundant (Video 2).

In light of these geological and ecological features, the area of the Mula di Muggia is recognized as an ideal study site for the neoichnology of barrier-island systems.

3. Materials and methods

The study area was inspected between 2009 and 2010; subtidal areas were explored with a kayak. Major geomorphological features were traced with a GPS unit, which was also used to georeference selected photographic and video documentation (Fig. 1). Burrow architecture was analyzed by resin casting and manual excavation, further refining the morphological description of Baucon (2008).

4. Marginal marine ichnology

This section presents the morphological, biological and ethological features of the major ichnotaxa. 16 incipient ichnotaxa were recognized and divided into morphotypes on the basis of burrow morphology and size, after which they are named. A descriptive classification scheme, partly based on Książkiewicz (1977), is adopted to organize the ichnotaxa, to be considered as incipient in conformity with Bromley (1996, p. 164). Trace distribution is qualitatively described in Table 1.

4.1. Branched structures

4.1.1. Thalassinoides form XL (very large)

Description: Burrow networks with multiple openings, one of which presents a large sediment mound (diameter: 15–25 cm). Tunnel

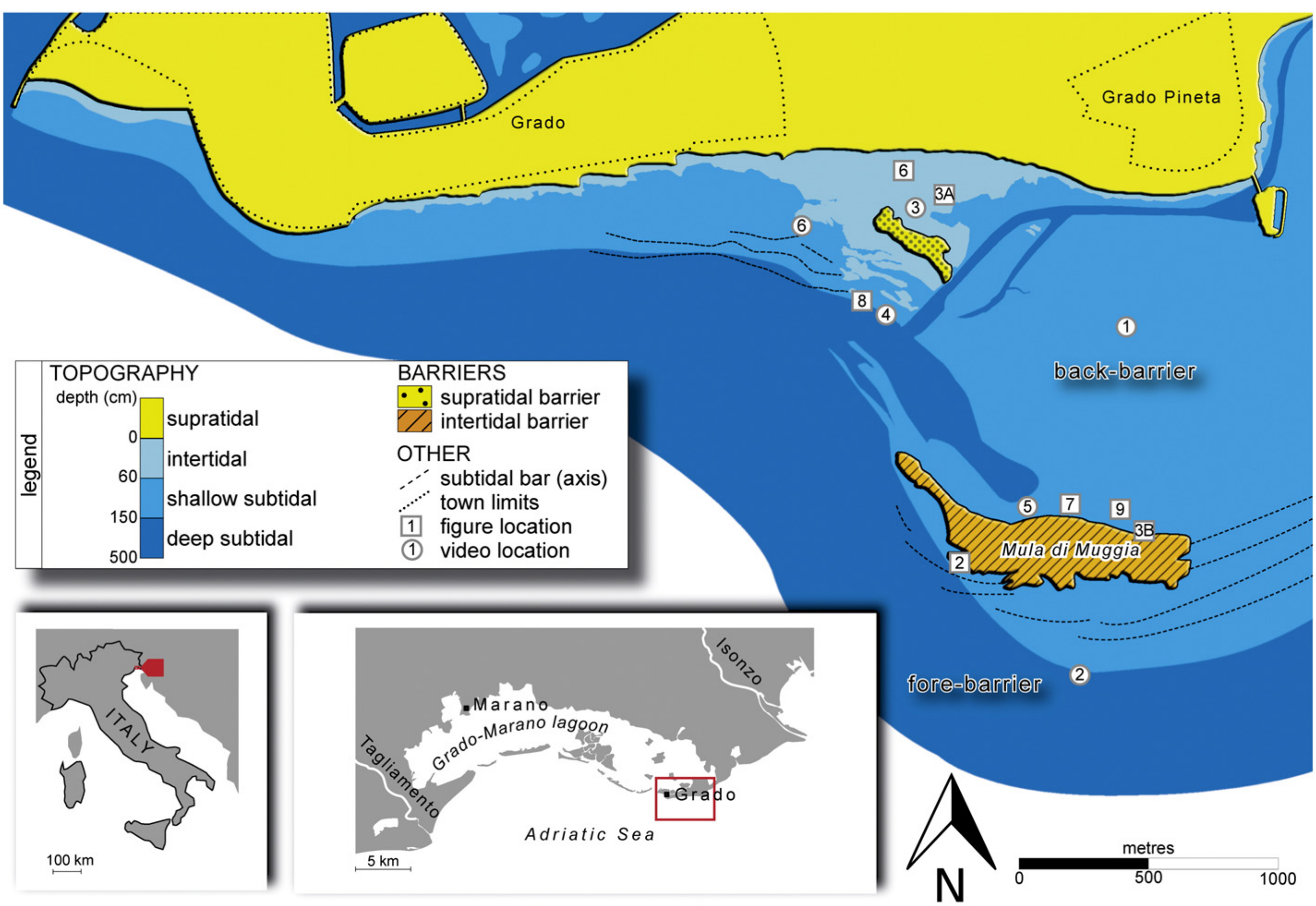

Fig. 1. Geographical and geological setting.

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