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Identification of tsunami-induced deposits using numerical modeling and rock magnetism techniques: A study case of the 1755 Lisbon tsunami in Algarve, Portugal

E. Font[a,*], C. Nascimento[a], R. Omira[a], M.A. Baptista[a,b], P.F. Silva[a,b]

[a] IDL-Faculdade de Ciencias da Universidade de Lisboa, Portugal
[b] ISEL/DEC, Lisboa, Portugal

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ABSTRACT

Storm- and tsunami-deposits are generated by similar depositional mechanisms making their discrimination hard to establish using classic sedimentologic methods. Here we propose an original approach to identify tsunami-induced deposits by combining numerical simulation and rock magnetism. To test our method, we investigate the tsunami deposit of the Boca do Rio estuary generated by the 1755 earthquake in Lisbon which is well described in the literature. We first test the 1755 tsunami scenario using a numerical inundation model to provide physical parameters for the tsunami wave. Then we use concentration (MS, SIRM) and grain size (χ_{ARM}, ARM, B1/2, ARM/SIRM) sensitive magnetic proxies coupled with SEM microscopy to unravel the magnetic mineralogy of the tsunami-induced deposit and its associated depositional mechanisms. In order to study the connection between the tsunami deposit and the different sedimentologic units present in the estuary, magnetic data were processed by multivariate statistical analyses. Our numerical simulation show a large inundation of the estuary with flow depths varying from 0.5 to 6 m and run up of ~7 m. Magnetic data show a dominance of paramagnetic minerals (quartz) mixed with lesser amount of ferromagnetic minerals, namely titanomagnetite and titanohematite both of a detrital origin and reworked from the underlying units. Multivariate statistical analyses indicate a better connection between the tsunami-induced deposit and a mixture of Units C and D. All these results point to a scenario where the energy released by the tsunami wave was strong enough to overtop and erode important amount of sand from the littoral dune and mixed it with reworked materials from underlying layers at least 1 m in depth. The method tested here represents an original and promising tool to identify tsunami-induced deposits in similar embayed beach environments.

1. Introduction

Tsunamis are unforeseeable phenomena and consequently one of the most devastating natural hazards in terms of human and economical losses. Since the tsunami of Sumatra in 2004, by far the largest natural catastrophe in human history, the worldwide scientific community has deployed numerous investigations of tsunami deposits to assess tsunami impact. Reconstruction of long-term frequency of paleotsunami is still hard to reach due to the weak conservation of the tsunami deposits in the geological record and to the difficulty in distinguishing them from storm deposits which have similar depositional mechanisms (e.g., Pratt, 2002; Shanmugam, 2006; Tapin, 2007; Dawson and Stewart, 2007; Morton et al., 2007). Despite their genetic differences, tsunamis and storms both cause brief coastal flooding with high overland flow velocities and strong abrasion and reworking of the nearshore materials. As most nearshore environments are composed by sand, mud and gravel, the distinction between tsunami and storm deposits remains even more difficult.

Here, we test a new method to identify tsunami deposits based upon numerical simulation and rock magnetism techniques coupled with statistical analyses. To test our method we choose the tsunami deposit generated by the 1755 Lisbon earthquake in the Boca do Rio estuary, in Algarve, southern Portugal (Fig. 1), which were dated by thermoluminescence (Dawson et al., 1995; Hindson and Andrade, 1999) and well described in the literature in terms of geomorphologic and sedimentologic features (Hindson et al., 1996; Hindson and Andrade, 1999; Loureiro et al., 2009). The Boca do Rio estuary is a peculiar case of beach embayment where storm waves generally do not overtop the littoral cliff thus providing excellent conditions to preserve the sedimentological record of the 1755 Tsunami.

* Corresponding author at: IDL-Faculdade de Ciencias da Universidade de Lisboa, Edificio C8, 3° andar, Campo Grande, 1749-016 Lisboa, Portugal.
Tel.: +351 913 782 645.
E-mail address: font_eric@hotmail.com (E. Font).

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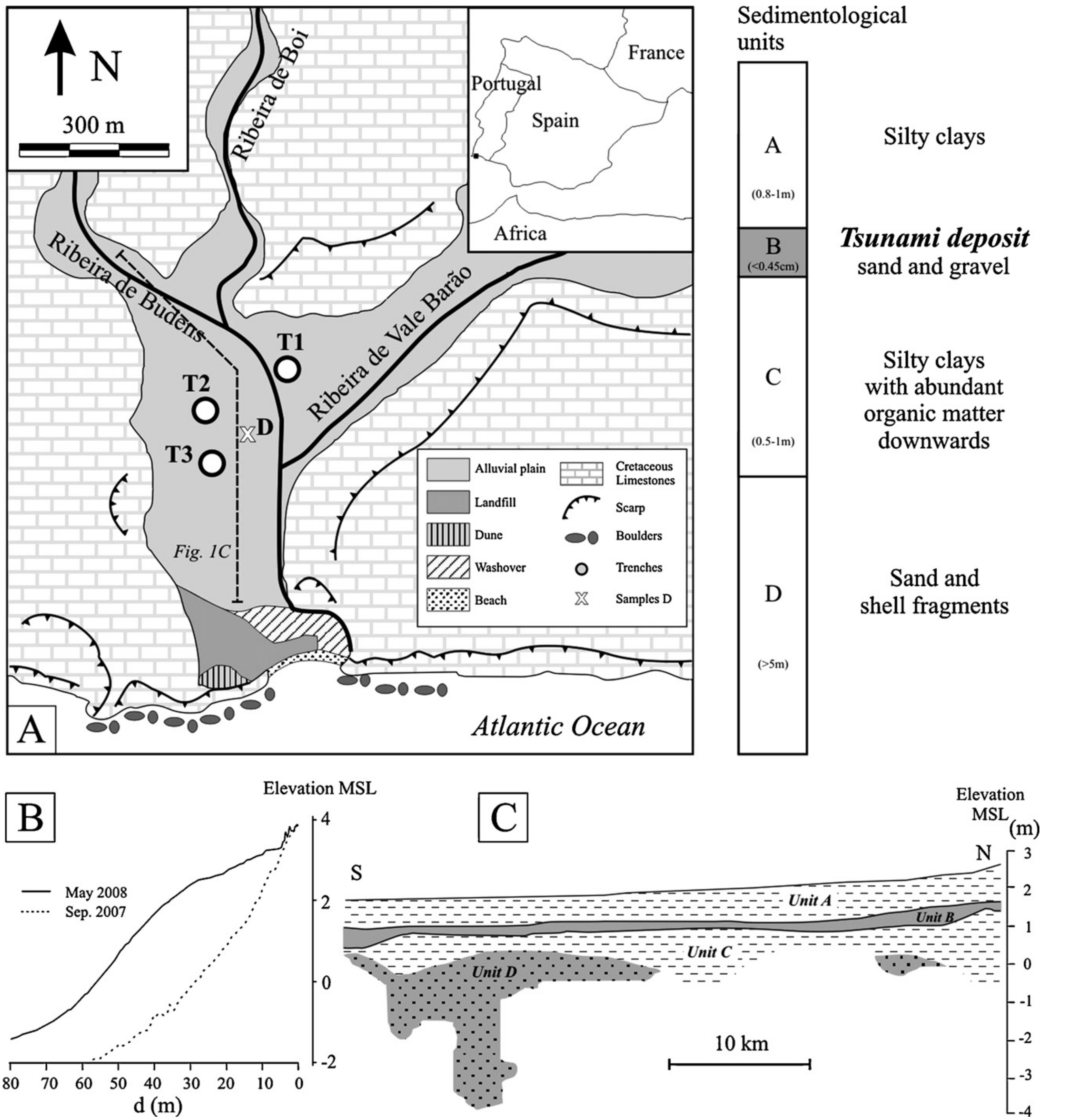

Fig. 1. (A) Geological and structural map of the Boca do Rio estuary and synthetic stratigraphic log (modified from Oliveira et al., 2009 and Hindson and Andrade, 1999); (B) morphology and elevation to mean sea level (MSL) of the sandy littoral dune of the Boca do Rio estuary from 2007 to 2008 (Loureiro et al., 2009); (C) vertical cross-section of the Boca do Rio estuary (Hindson and Andrade, 1999; Oliveira et al., 2009).

Recently, Omira et al. (2009a) developed a new numerical inundation model, based on the COMCOT code (Liu and Cho, 1994; Liu et al., 1995, 1998), for the Gulf of Cadiz and the region of Casablanca, Morocco, that could be used to simulated the inundation of the Boca do Rio estuary and to provide physical parameters (i.e. maximum run up, inundation depths and current velocities) for the 1755 tsunami wave. These physical parameters could be further linked to the depositional mechanisms (erosion, transport and deposition) of the tsunami wave by using rock magnetic techniques. Variations of magnetic properties in continuous stratigraphic sections usually reflect changes in the detrital component mineralogy which is largely influenced by cyclic climatic variations (e.g., Ellwood et al., 2007, 2008). In the case of an acyclic event such as bolide impact or even tsunami and storm, which are not controlled by Milankovitch cycles, the brutal change of detrital input into the sedimentary column is easily depicted by an abrupt shift of MS values and thus represents an excellent tracer for our purpose. In counterpart, nature, morphology and distribution of magnetic particles of the tsunami deposit can inform about the origin of the material. Finally, multivariate statistical analyses of magnetic data permit to state the connexion between the tsunami deposit and the underlying layers. Finally, we propose a scenario for the 1755 tsunami deposit that could be used for further investigations of tsunami deposits in embayed beach environments.