

Coastal hazards from slope mass movements: Analysis and management approach on the Barlavento Coast, Algarve, Portugal



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ABSTRACT

The Barlavento Coast, Algarve, Portugal, is dominated by rocky sea-cliffs, cut on Miocene calcarenites which evolves through intermittent and discontinuous events of slope mass movements, along a 46 km cliff front. Here, the main coastal geologic hazards result from the conflict between human occupation and sea-cliff recession. Most of the research on the dynamics of the cliffs has been directed to the risk with the aim of defining long term set-back lines, for a preventive planning of the cliff top occupation. Little attention has been given to the hazard associated with mass movements on bathing beaches backed by sea-cliffs. This article presents the results of a field inventory of 244 slope mass movements single events, collected in a rocky shore with tens of touristic pocket beaches, covering an nineteen year time span (1995–2014). Results show that landslides have seasonal pattern with higher incidence in the period between winter and early spring. More than 15% of movements occur during the Easter holidays (April) and 4% of landslides occur during the official bathing season (June–September). The spatial distribution of landslides shows that only 22% of the mass movements occur in capes and headlands, while 78% occur on the beaches, which demonstrates that the beaches are real hot spots of risk. Based on the size distribution of slope mass movements runout ratio (the ratio between the radius of the base of the cone of and the height of the movement) a table of levels of security and hazard on beaches was built. Security levels enable the definition of cartographic hazard areas on beaches which can be provided to the beach users on information boards at the beach entrance.

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1. Introduction

Algarve coastal region, with 451,000 inhabitants in 2011, is the premier tourism destination of Portugal, with a mean annual of 15 million overnight stays through the 2002–2011 period (INE, 2012). Almost 90% of the visitors' reasons of staying in the Algarve coast are leisure, recreational and holiday (INE, 2012). The Barlavento Coast between Lagos and Albufeira (Fig. 1) is the core touristic area and receives 60% of the Algarve visitors attracted with the “sun and beach”, which is the Algarve's top touristic product. About 50% of the Algarve visitors stay and bathe in beaches backed with rocky sea cliffs of the Barlavento Coast.

Over the last three decades, there has been record of several accidents caused by the collapse of sea cliffs cut on Miocene rocks. On 22 March 1998, a Portuguese man was killed while fishing at the cliff edge at the Maré das Porcas site, when a sudden planar landslide dragged him down together with a volume of $2 \times 10^4 \text{ m}^3$ falling material; on 7 October 2000, three Swiss tourists were

injured by a block fall (volume 2 m^3) on the Inatel beach; on 21 August 2009 an instantaneous topple (volume $1 \times 10^3 \text{ m}^3$) on a sea stack killed five Portuguese tourists and injured another two, resting on the cliff base on the Maria Luísa beach; on 26 May 2010 a four year Irish kid was slightly wounded on the Vau beach hit by the debris of a landslide (Fig. 2, volume $2 \times 10^2 \text{ m}^3$); on 11 October 2010 a German tourist was injured on the Beijinhos beach, hit by blocks of a small landslide (volume 1 m^3). This record shows that the average number of accidents resulting directly from cliff collapse of sea cliffs is 2 event/decade, causing two fatalities and two injuries each decade.

Searching for the accidents of the cliff top walkers, mostly sightseers and fishing anglers, in the decade 2003–2012, Teixeira and Dóres (2013) identified a record of 50 accidents on the Barlavento rocky cliffs with 11 fatalities and 41 injured. 45% of the victims were foreigner tourists. Although statistically not very significant when compared to accidents resulting from the use of the top of the cliffs, accidents caused by landslides on beaches have great impact on public opinion. While accidents of suicide or death of fishermen by falling from the cliffs typically occupy small news in local newspapers, after the collapse recorded in Maria Luísa beach

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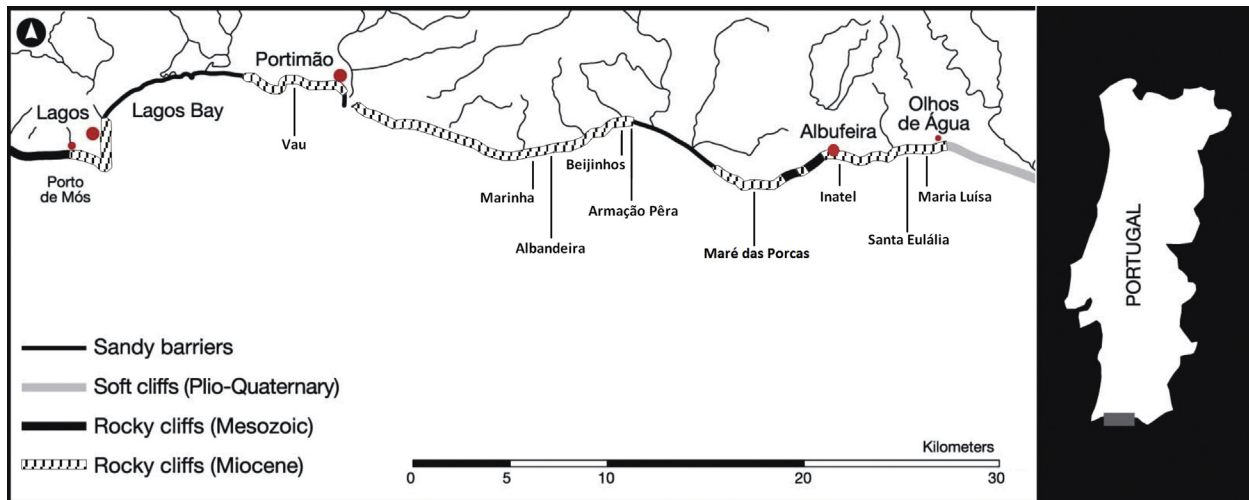


Fig. 1. Barlavento coast. Study area.

the accident was the subject of daily news in all national newspapers for more than a month. Five years on, the accident is still remembered every year at the start of the bathing season (June–September).

Slope mass movements on steep rocky sea cliffs are instantaneous phenomena with virtually no warning. The velocity of the movement is typically over 5 m/s, within the landslide velocity class 7, the extremely rapid events of the Cruden and Varnes (1996) classification. On the Barlavento rocky coast, where sea cliffs are subvertical with height varying from 5 to 40 m, the duration of the slope mass movements lies in a narrow time window of 1–2 s. The instantaneous nature of the phenomenon precludes any action to minimize the damage after the onset of the collapse process. On steep subvertical rocky sea cliffs prone to slope mass movements, the actions to minimize risk and damages are therefore exclusively based on prevention.

The first step in the implementation of prevention is the knowledge and definition of the areas potentially affected by a mass movement, i.e. the spatially definition of hazard areas. Hazard areas, limited by hazard lines, correspond to areas parallel to the shoreline where, in a pre-defined period, it is likely that effects of slope mass movements will be felt (Fig. 3).

Most studies and bibliography, oriented strand planning, focuses on the land hazard areas at the top of the cliffs worldwide

(see, for example, Hall et al., 2002; Lee and Clark, 2002; Moore and Griggs, 2002; Del Rio and Gracia, 2009; Stravou et al., 2011; Epifânio et al., 2013) and on Algarve (Marques, 1994, 1997, 2003; Teixeira, 2003, 2006; Bezerra et al., 2011; Marques et al., 2011; Nunes et al., 2009). Very few papers deal with sea hazard areas on sea cliffs (Marques, 2009), although studies on the identification of risk areas associated with damage caused by slope mass movements are very common in land areas (e.g. Copons et al., 2009; Michoud et al., 2012).

In the case of touristic areas centered on beaches backed by cliffs, the sea hazard area has particular interest in that it is in this area where accidents occur with people affected by the debris of a mass movement. In Portugal, beach tourism is an important economic activity, all the coastal plans regulations include a seaward hazard area on beaches backed by sea-cliff extending seawards from the cliff toe, where beach support structures are interdicted (Marques, 2009). On the study area coastal plan regulations, in force since 1999, a sea hazard area is defined on beaches backed by sea cliffs with a width of 1.5 times the cliff height and corresponds to the maximum extent of cliff failures debris displacement near the toe.

In this paper we present the results of slope mass movements inventories gathered on Barlavento Coast sea cliffs, for the last nineteen years (1995–2014), we assess the adequacy of the legal



Fig. 2. Rock fall on the Vau beach occurred in the 26 May 2010 (location on Fig. 1); mean width (W_m) = 2.5 m; runout ratio (R) = 0.8.

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