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Research Paper

Optical dating of clastic deposits generated by an extreme marine coastal flood: The 1755 tsunami deposits in the Algarve (Portugal)

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ABSTRACT

Identification of past tsunamis is important for risk assessment and management of coastal areas. Obtaining accurate and precise ages of sediments originating from such extreme marine coastal floods is crucial for a reliable estimation of the recurrence interval of these often devastating events. We present here the results of quartz optical dating and ^{14}C dating of two sites (Boca do Rio and Martinhal) on the Algarve coast (southern Portugal). These sites contain deposits of the great tsunami of November 1, 1755. The sections were described using sedimentological techniques; at both sites tsunami-laid sands and gravels were identified, intercalated between estuarine muds. Quartz luminescence ages from these sedimentary successions were derived using standard SAR-OSL dating using multi-grain sub-samples. A multiple sampling strategy was employed with several samples taken from the AD 1755 tsunami deposit and from the sediments bracketing the tsunami layer. Our SAR-OSL protocol was shown to be appropriate using dose recovery measurements (measured/given dose ratio of 1.004 ± 0.007, $n = 165$). The several OSL ages from the 1755 tsunamigenic deposits are internally reproducible but yield age overestimates of between 20 and 125% (60–310 years respectively); this is in agreement with values reported in the literature for similar deposits. The age overestimation of the tsunami-laid sands is presumably due to the rapid erosion and deposition of older sediments, with insufficient light exposure for complete bleaching during the tsunami event itself. The absence of significant bleaching during the tsunami is also suggested by the shape of the dose distributions based on sub-samples made up of only about 100 grains. Analysis of the distributions with the minimum-age model seems to yield the expected age for two of the three distributions. It is important to note that age offsets of a few tens of years to a few hundred years rapidly become insignificant when dating older (>1 to few ka) tsunami layers.

1. Introduction

Tsunamis can cause severe coastal erosion, but also transport and deposit different sized particles, ranging from clay to boulders, inland (Dawson, 1994). Establishing a chronology of tsunami events preserved in the geological record (e.g. Morales et al., 2008) is important for the estimation of the average recurrence interval and time dispersion of extreme marine coastal floods and in the assessment of seismic hazards of a region. Luminescence dating methods have previously been applied to tsunami deposits using thermoluminescence (TL; e.g. Bryant et al., 1996), infrared stimulated luminescence (IRSL; e.g. Huntley and Clague, 1996; Ollerhead et al., 2001) and optically stimulated luminescence (OSL; e.g. Banerjee et al., 2001).

The earthquake of 1st November 1755 was of high magnitude (8.5) and generated a tsunami (Baptista et al., 1998a,b) that flooded the Algarve coast (southern Portugal) and deposited sediments in the lowlands of Boca do Rio (BDR) and Martinhal (MRT). At Boca do Rio the ages reported for those sediments in several independent studies are quite diverse (e.g. Dawson et al., 1995; Hindson and Andrade, 1999; Hindson et al., 1999; Allen, 2003). At Martinhal, the ages reported by Kortekaas and Dawson (2007) were found to be problematic because they are not in stratigraphic order, leading the authors to state that in their study luminescence dating was not a reliable method to date the 1755 tsunami layer.

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In this paper, we test both spatially and stratigraphically the application of standard large aliquot quartz SAR-OSL dating to both the 1755 tsunami deposits and to the bracketing sediment units at the Boca do Rio and Martinhal sites. The twenty-one OSL and four ^{14}C ages from our study are compared with previously published luminescence and ^{14}C ages for the same sites and with the known age of the deposit (250 years). The purpose of this work is to test the accuracy of standard large aliquot quartz SAR-OSL for dating the 1755 tsunami layer on the Portuguese coast, and by implication, for dating older deposits of similar origins.

2. Sites and sampling strategy

The Boca do Rio and Martinhal wetlands are separated from the sea by sand-shingle beach barriers, which confine alluvial plains that dry out during the summer but are periodically flooded by freshwater during winter.

An eyewitness reported the 1755 event as having occurred on a bright sunny morning during flood tide, producing on the Algarve coast a run-up that was estimated as ca. 11–15 m. According to historical records, the tsunami flooded ca. 1 km inland at Boca do Rio (Fig. 1a). A tsunami-laid sand wedge, <50 cm-thick, containing shell fragments, cobbles and boulders with borings of marine endolithobionts represents the 1755 event at this location (Dawson et al., 1995; Silva et al., 1996). In our study two trenches were dug at BDR, a southern trench (BDR-ST) and a northern trench (BDR-NT), located 300 m and 600 m from the modern beach respectively (Fig. 1a). The tsunami sand was found at depths of 100–120 cm (BDR-NT) and 70–100 cm (BDR-ST), intercalated with estuarine muds that rest upon more open-marine sands. Three OSL samples were taken laterally several meters apart in the tsunami layer in the southern trench and four in the northern trench; OSL samples were also collected from the sediments above and below the tsunami layer. A schematic description of the stratigraphy and the OSL sample locations is given in Figs. 2 and 3.

The trench excavated at Martinhal (Fig. 1b), located close (~100 m) to the sampling location of Kortekaas and Dawson (2007), showed a more diverse stratigraphy. Here, multiple shell-rich sand and gravel layers were identified within estuarine deposits, of which at least one, according to witness reports, should correspond to the 1755 event. The characteristics of the coarser sediments indicate a marine source (good sorting, high roundness of quartz grains, presence of marine bioclasts, etc.), consistent with having been deposited by an extreme marine coastal flood. We identify this layer with the 1755 tsunami deposit. Three OSL samples were taken in this marine layer and three in the silt and sand layers below (Fig. 4).

3. Published absolute age information

Following the first study of the upper Holocene at Boca do Rio by Andrade et al. (1994), Dawson et al. (1995) described in detail the lithostratigraphic units at a trench close to our BDR-ST. They characterized the units as follows from the surface to depth: unit A – dark red/brown silt that towards its base changes to an organic silty clay, up to 0.8 m thick; unit B – mainly medium sand but sometimes grading from very fine to coarse sand at its erosive base, containing marine macro- and micro-fossils, 0.1–0.4 m thick; unit C1 – brown organic clay-rich silt containing fossil stems and rootlets and occasional fragments of charcoal and shells, 0.1–1.0 m thick; unit C2 – brown/black and organic silty clay, 0.1–1.0 m thick; unit D1 – medium sand, 0.1–3.2 m thick; unit D2 – bioclastic gravel, >0.5 m thick. For unit B, identified as the tsunami layer, a thermoluminescence age estimate of 260 ± 60 yrs (AD1734 ± 60) was listed (no sample code was provided); radiocarbon dates (accelerator mass spectrometry – AMS) of units C1 and C2 yielded 1890 ± 60 yrs cal BP (Beta-68853) and 1210 ± 60 yrs cal BP (Beta-68854) (Dawson et al., 1995) (Fig. 2).

Hindson et al. (1999), in the same Boca do Rio area close to BDR-ST, provided detailed foraminifera and ostracod analyses, but also an OSL chronology (OSL ages before 1995, in years) based on seven samples collected from a trench: BDR-A (587 ± 38), BDR-B (194 ± 76), BDR-C1 (1236 ± 540), BDR-C2 (1363 ± 420), BDR-D1 (1815 ± 411), BDR-D2 (1944 ± 280) and BDR-D3 (2320 ± 617); samples BDR-D1, BDR-D2 and BDR-D3 were collected from the unit D1 defined by Dawson et al. (1995) and provided ages that are in stratigraphic order (Fig. 2). For units A and C the 4–11 μm polymineral fraction was used and for units B and D the 180–225 μm quartz fraction. Equivalent dose determination was done by the additive-dose method and a halogen light source; luminescence detection was in the UV through a U-340 filter pack. The dosimetry was based on on-site gamma spectrometry and thick source beta counting. An estimate of 5% was used for the water content, although the authors acknowledge that this may be too conservative for their environment.

Allen (2003) made a palaeoecological analysis of a 3 m core from the same lowland close to BDR-NT. Standard radiocarbon dates were determined for three organic silts (numbers in the sample code denote depth in cm): 1062 ± 150 yrs cal BP – BDR135-138, 936 ± 140 yrs cal BP – BDR146-148, 1171 (1304-966) yrs cal BP – BDR253-254; a shell hash, dated as 8955 (8994-8660) yrs cal BP – BDR286-294, was rejected because it was considered to be not *in situ*. An AMS radiocarbon date on a shell yielded 1046, 1040, 974 (1061-935) yrs cal BP – BDR253-254 (Fig. 3).

For Martinhal, the published information is not easy to interpret because of the complex stratigraphy in the Martinhal lowland (spatially very variable), which does not allow us to reliably connect both stratigraphies. Furthermore, the OSL results presented by Kortekaas and Dawson (2007) were considered problematic by the authors (also no experimental details are given). Because of the difficulty of relating both studies, we restrict ourselves to reporting the OSL results of Kortekaas and Dawson which were obtained on the two samples taken in the layer identified by them as being deposited by the 1755 tsunami: one sample (MRT3) yields an of 3199 ± 2008 yrs whereas the other sample (MRT2) yields and age of 74 ± 45 yrs (Fig. 4).

4. ^{14}C dating

In our study, a radiocarbon age (Beta83686 – 2250 ± 60 yrs BP, 1515 yrs cal BP) was obtained on an endolithic shell extracted from a limestone boulder within the 1755 tsunami layer in a location near BDR-ST (Fig. 2).

From unit C1, at a depth of 1.96 m in a pit located close to BDR-NT, three AMS radiocarbon results were obtained from the same estuarine mud sample: Beta241183 – 1400 ± 40 yrs BP (930 yrs cal BP) from a shell; Beta241186 – 1480 ± 40 yrs BP (1360 yrs cal BP) from particulate carbon; Beta241187 – 370 ± 40 yrs BP (470 yrs cal BP) from charcoal (Fig. 3).

5. Luminescence dating

5.1. Sample preparation and measurement details

Quartz grains in the range 180–250 μm were extracted from the inner part of 30 cm long (7.5 cm diameter) PVC or stainless steel tubes using conventional sample preparation techniques (sieving, 10% HCl, 10% H_2O_2, 40% HF). The grains were mounted on stainless steel discs using silicon spray. All measurements were made on large aliquots containing several thousands of grains, except where