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Research Paper

The potential of using K-rich feldspars for optical dating of young coastal sediments – A test case from Darss-Zingst peninsula (southern Baltic Sea coast)

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ABSTRACT

The potential use of a modified elevated temperature post-IR IR (pIRIR) SAR protocol for K-rich feldspar was tested for seven late Pleistocene and Holocene samples from a coastal sediment succession from the southern Baltic Sea (Darss-Zingst peninsula). This modified pIRIR protocol observes a pIRIR signal at 180 °C after the IRSL measurement at 50 °C. After thorough performance testing, equivalent doses (D_e) were measured and corrected for the residual doses and fading. The results showed that thermal transfer and residual doses are more significant for pIRIR signal than for quartz OSL and IRSL signal. The calculated K-feldspar ages (IRSL and pIRIR) were then compared with quartz-SAR and two independent radiocarbon ages.

The ages of the investigated sediments range from the late Pleistocene (~13.5 ka) to a few hundred years. The laboratory-fading rate of the pIRIR signal was significantly lower (*g*-value of 0–2%/decade) than that of the IRSL (g-values of 3–10%/decade). We observed a systematic overestimation of fading-corrected IRSL ages based on high g-values (>5%), whereas the pIRIR ages showed a good agreement with the quartz ages and with the radiocarbon ages for the well-bleached mid-Holocene and the late Pleistocene samples, suggesting that our modified pIRIR protocol is suitable for well-bleached young sediments. For the incompletely bleached uppermost samples the minimum age model (MAM) was applied. For these samples it is concluded that both IRSL and pIRIR ages derived from K-feldspar overestimated the true burial age.

1. Introduction

Sediment dating is an important tool in coastal research because it contributes to the unravelling and understanding of the dynamics and processes along our coasts. Successions of beach ridges, foredune ridges and/or coastal dunes provide high-resolution chronologies for the Holocene coastal evolution and hence the development of coastal landforms e.g. spits, barrier-spits and barrier islands. Until recently, most chronologies of coastal sediment successions, for example along the southern Baltic Sea coast, were mainly based on radiocarbon data derived mostly from the coastal hinterland and a limited number of archaeological findings (e.g. Lampe, 2005; Hoffmann et al., 2005). But radiocarbon based chronologies are often incomplete and complicated due to the absence of suitable non-reworked organic material (e.g. peat, wood or shells) and calibration problems within the last 350 years (Hua, 2009).

Luminescence dating methods provide an excellent chronological tool in coastal environments (e.g. Jacobs, 2008) because they can provide burial ages for sand- or silt-sized sediments for the Holocene period. In recent years, optical dating of quartz applying the single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2000) is commonly used for geochronological studies in a sand dominated coastal environment (e.g. Ballarini et al., 2003; Madsen et al., 2005, 2007, 2009; Nielsen et al., 2006; Lopez and Rink, 2007; Roberts and Plater, 2007). Quartz optical dating has also been applied frequently and successfully to sediments younger than 1000 years (see recent review by Madsen and Murray, 2009). However, in some regions of the world the use of quartz as a dosimeter is not possible due to a poor OSL sensitivity of the quartz minerals (e.g. Preusser et al., 2006; Hülle et al., 2010; Steffen et al., 2009; Kunz et al., 2010). Furthermore, Davids et al. (2010) pointed out that the quartz OSL signal of very young samples is dim and produces a broad distribution of equivalent doses (D_e) due to a poor signal to noise ratio. The dim OSL signal of very young quartz samples also limits the use of small-aliquot techniques for samples from the recent past, necessary to detect incomplete bleaching

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(Madsen and Murray, 2009). In addition, Davids et al. (2010) as well as Madsen et al. (2009) identified problems of broad D_e distributions, if the dosimetry is complex due to inhomogeneously-deposited sediments and/or large variations in the water content.

Wallinga et al. (2000) and Blair et al. (2005) developed the single-aliquot regenerative-dose protocol for infrared-stimulated luminescence (SAR-IRSL) of coarse-grain feldspar. Li et al. (2007a) and Davids et al. (2010) demonstrated that SAR-IRSL of K-feldspars gives more reproducible and precise D_e values than quartz for their Holocene dune sand and coastal overwash sediment. Both authors interpreted this to be caused by the higher OSL sensitivity of feldspar grains and because the internal potassium content of K-feldspars reduce the impact of variations in the external dose. Nevertheless, ages derived from SAR-IRSL dating of K-feldspars need to be corrected for anomalous fading. Wallinga et al. (2007) showed the limitations of the assumptions made by the common fading correction procedures (e.g. Huntley and Lamothe, 2001; Lamothe et al., 2003). Wallinga et al. (2007) also reported a decreasing fading rate (g-value according to Aitken, 1985) as a function of dose rate. In contrary, Li et al. (2008b) found a negative correlation between dose rate and the amount of underestimation of feldspar ages, suggesting a higher fading rate might be related to a higher environmental dose rate.

In this paper we test the potential of an elevated temperature post-IR IR (pIRIR) SAR protocol which was originally proposed by Thomsen et al. (2008) and recently applied by Buylaert et al. (2009). This protocol measures a standard IRSL signal at 50 °C as well as a pIRIR signal at an elevated temperature for dating of young coastal sediments. The pIRIR signal is supposed to be much less affected by anomalous fading (Thomsen et al., 2008; Buylaert et al., 2009). However, signal resetting might be a problem for the pIRIR protocol. Buylaert et al. (2009) reported residual doses of less than 2 Gy which do not affect their old samples but are important for young samples. In order to apply the pIRIR protocol to young sediments it should make use of a lower preheat temperature than that originally suggested to minimize thermal transfer. Furthermore, the subtraction dating technique (e.g. Aitken, 1985; Davids et al., 2010) is applied to test the reliability of this method. The subtraction method uses the difference between the quartz and the feldspar D_e (Aitken, 1985) and was recently applied by Davids et al. (2010) for SAR-IRSL and SAR-OSL dating of feldspar and quartz from hurricane overwashed sediments. In this study, we measured seven samples from a sediment core from the Darss-Zingst peninsula (southern Baltic Sea coast, Germany) having an age range from about 13.5 ka to a few hundred years. We compare IRSL and pIRIR ages with ages obtained from SAR measurements of quartz and the subtraction method. Radiocarbon dating of three organic layers within the sediment core is used as an independent age control. Only two of the radiocarbon dates are used because the third one is regarded as unreliable. The aim of this study is to test and modify the pIRIR protocol to make it suitable for dating of young coastal sand-sized samples.

2. Geological setting and samples

2.1. Geological setting

The drilling site of Zi-43 is located at the Darss-Zingst Peninsula (NE Germany) which belongs to the southern Baltic Sea coast (Fig. 1). The Darss-Zingst peninsula is a part of the Fischland-Darss-Zingst island chain. The drilling was done in the east of the artificially closed coastal inlet "Prerowstrom" which subdivides the Darss from the Zingst, and in the west of the sampling sites Zingst-Osterwald and Windwatt of Reimann et al. (2010) where they obtained OSL ages of ~1500–1900 years and ~40–900 years from the beach ridge successions, respectively (Fig. 1). The development of the southern Baltic Sea coastline started with the Littorina transgression at ~8 ka (Janke and Lampe, 1998; Lampe, 2005; Hoffmann et al., 2005). The pre-Littorina relief was mainly shaped by the Weichselian glaciation during the late Pleistocene. Morainic and glaciofluvial/glacilacustrine depositions were modified by glacial tectonic and fluvial processes and formed the basement and sediment supply for the coastal evolution (Naumann et al., 2009). Between 8 and 6 ka the sea level rose rapidly with rates of up to 2.5 cm/a (Kliewe and Janke, 1991) resulting in a level of around 2 m below the present sea level at about 6 ka. The cliffs from the Pleistocene headlands were eroded and the morphological depressions were subsequently filled with sediment. The shallowing of the depressions and the decrease of the sea level rise since 6.5 ka (Schumacher and Bayerl, 1999; Hoffmann et al., 2005; Lemke, 2005; Lampe, 2005) led to the development of spits and barrier-spits between the islands isolating bays and lagoons from the open sea. These processes formed the typical southern Baltic coast with a system of beach ridges and dunes at the front and peatlands in the coastal hinterland.

2.2. Samples and preparation

The core was taken with a hydraulic powered extracting tool. Black PVC liners with a diameter of 80 mm were used for coring to avoid light exposure of the luminescence samples. The core (Zi-43, Fig. 2) contains a sediment succession of ~5.3 m. The succession starts at the bottom with late Pleistocene glaciofluvial and/or glaciolacustrine fine sand. Between 4.9 m and 4.5 m a peat was developed with an obvious and undisturbed soil development underneath (Fig. 2). It is therefore very likely that this peat is "in situ". Above this first peat layer, the Holocene succession started with shallow water or coastal fine sand between 4.5 to 2.5 m. This sand is very quartz-rich and has only low shell content. Interstratified organic and peat layers were also found and the most pronounced one (at about 4 m) was sampled for radiocarbon dating (Fig. 2). As this peat horizon has a very sharp border to the Holocene sand beneath, we assume it is not "in situ". The succession continues with an organic-silicate gyttja representing slack-water conditions, which is related to the closing or shallowing process of the "Prerowstrom", and the isolation from the open sea. On the top of the succession a quartz-rich fine sand layer follows, which is structured by interstratified thin organic or peat layers. Altogether, seven luminescence samples (W-Zi 1-7) were taken from the glaciofluvial/glaciolacustrine, the shallow marine, and the cover sand units (Fig. 2). Samples for dose rate determination were taken from each sediment surrounding the luminescence sample. In addition, we took three samples from the two peat layers and the gyttja for radiocarbon dating.

The Zi-43 core (Fig. 2) was opened, sub-sampled, and the samples were prepared in the luminescence laboratory under subdued red light conditions. The seven samples were dry-sieved to recover grains either 100–150 μm (Zi-W 1, 3–7) or 150–200 μm (Zi-W 2) in diameter. The sand was treated with HCl to dissolve carbonate, with $Na_2C_2O_4$ to dissolve aggregates, and with H_2O_2 to remove organic matter. The quartz minerals were then density separated by a heavy liquid (sodium polytungstate) from the feldspars (<2.62 g/cm^3) and the heavy minerals (>2.70 g/cm^3). Using the same method, the K-rich feldspars (<2.58 g/cm^3) were separated from the Na-rich feldspars (>2.58 g/cm^3). The quartz grains were then treated with 40% HF for about 60 min to etch the outer surface of the grains, to avoid a contribution of the α-irradiated outer part of the quartz mineral, and to remove remaining feldspar minerals. After HF-etching, the quartz grains were sieved again with a 100 μm (Zi-W 1, 3–7) and 150 μm (Zi-W 2) mesh to reject small particles. The K-rich feldspar separates were not treated with HF. The samples for dose rate determination were dried and homogenised.