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Research Paper

Optical dating of tidal sediments: Potentials and limits inferred from the North Sea coast

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ABSTRACT

The accuracy of optical ages derived from tidal sediments depends largely upon the transport processes. These processes constrain the degree of bleaching by the time of deposition and the choice of grain size for dating. This study looks at flow regime, sediment bedding, particle size and suspended sediment concentration (SSC) over tidal flats in order to identify the tidal sub-environment from which reliable multigrain optical ages are most likely to be achieved. The resulting conceptual model is then compared with empirical OSL data obtained from Holocene sediments of the southern North Sea tidal coastal plain of continental Europe. Optical dating of the tidal sediments included single-aliquot-regenerative dose protocol applied to multigrain aliquots of fine sand and fine silt, statistical analysis using weighted skewness, standardised kurtosis and over-dispersion. It is inferred from the model that smaller grains should be better bleached than larger grains. However, because transport and deposition processes are extremely variable in both space and time, unequivocal "bleaching rules" could not be assigned to a particular tidal sub-environment. In this context more than 85% of our samples return accurate ages and around 13% of our optical ages are overestimated when compared with ages from established well-constrained stratigraphic frameworks. The empirical study confirms the concept of "variable bleaching rules": both accurate and inaccurate ages are obtained from silty and sandy OSL samples regardless of the sub-environment and well-bleached samples may be obtained from all tidal sub-environments. Although our study is based on multiple-grain aliquots it also shows that an independent statistical treatment of equivalent dose data is an indispensable procedure to detect and correct for insufficient bleaching.

1. Introduction

Optical dating is an alternative to radiocarbon dating for sediments lacking appropriate organic material for radiocarbon dating. With tidal sediments the technique is of particular interest as organic material is barely available or of uncertain relation to the depositional event, thus yielding inaccurate or erroneous ages (e.g. Baeteman, 2008). Dating Holocene coastal marine sediments is required for any sea-level study or palaeoenvironmental reconstruction that, for example, aims to determine the response of coast to sea-level trends in order to assess the future sensitivity to and impacts of sea-level rise. Hence, there is considerable scope for a more detailed study on the performance of the optical dating technique on tidal sediments and the reliability of optical ages for palaeoenvironmental reconstruction.

In a tidal environment the accuracy of the optical ages depends upon the processes of transport and deposition, sediment composition, sedimentation rate, the nature of wetting and drying, and post-depositional radionuclide mobility. The specific challenge for OSL dating is derived from the degree of bleaching at time of deposition and from availability of the dosimeter in the appropriate grain size. We address here the depositional processes on a tidal flat with regard to flow regime, sediment bedding, particle size and suspended sediment concentration (SSC) in order to establish a generic sedimentary sub-environment where sufficient bleaching is most likely and, hence, dating more likely to be successful. The resulting conceptual model is compared with published (Mauz and Bungenstock, 2007) and new OSL data from Holocene sediments obtained from the southern North Sea coast (French, Belgian and German coasts).

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For the Belgian coastal plain an exceptional sedimentary data set from closely-spaced boreholes is available, enabling reconstruction of its Holocene evolution in great detail in both time and space (Baeteman and Declercq, 2002; Baeteman, 2008). The accuracy of the OSL ages may then be assessed by comparing the OSL ages resulting from an independent statistical protocol (Bailey and Arnold, 2006; Arnold and Roberts, 2009) with the expected ages. We focus exclusively on the bleaching of Holocene tidal sediments for OSL dating and do not touch upon general OSL dating issues (e.g. saturation and other properties of the dosimeter).

2. Previous studies

Plater and Poolton (1992) studied fine-silt feldspars using infrared stimulated luminescence (IRSL, 940 nm) and thermoluminescence (TL). The samples were extracted from a sediment core that showed a change in environment from the high-water mark to the low-water mark of the mudflat and a short-lived reversal to more marine condition probably caused by a storm surge. For IRSL the authors find well-bleached feldspars in the upper and lower part of the mudflat while the residual TL progressively increases with decreasing daylight exposure time during the intertidal period linked to altitude on the tidal flat. Clarke and Rendell (2000) examined the fundamental characteristics of IRSL in intertidal sediments, and Bailiff and Tooley (2000) dated alternating marine and freshwater sediments using silt-sized feldspars. With an average uncertainty of around 14% the IRSL ages are generally consistent with radiocarbon ages derived from intercalated peat. Bailiff and Tooley's study highlights important issues arising from intertidal sediments such as changing water content and the presence of unsupported uranium alongside organic sediment components. Richardson (2001) undertook a comprehensive study on bleaching in tidal environments showing that feldspars deposited in intertidal mud and in saltmarsh are not bleached on a multiple grain aliquot level. Hong et al. (2003) studied a sandy tidal flat at the southwest coast of the Korean peninsula and find well-bleached K-rich feldspars and stratigraphically consistent IRSL ages between ~40 a and 120 a. Madsen et al. (2005) studied a tidal mudflat in the northern part of the Danish Wadden Sea and compared the optical ages with ^{210}Pb and ^{137}Cs data. These authors tested the reliability of quartz optical ages, finding well-bleached fine sand quartz grains (90–180 μm) in the mudflat and optical ages spanning ~7–315 a, which are in agreement with the independent age control. This study made detailed considerations on the environmental radioactivity in relation to water and organic matter content. The calculation of the environmental dose rate accounted for excess ^{210}Pb and changing beta and gamma dose to which quartz grains are exposed in a constantly accreting sediment setting. Boomer and Horton (2006) used IRSL ages derived from lower to upper intertidal mudflats to reconstruct sea-level index points. All ages presented in this study are in stratigraphic order and in accordance with the radiocarbon ages of the underlying peat. Roberts and Plater (2005, 2007) dated Holocene tidal flat and subtidal shoreface deposits (125–150 μm and 150–180 μm quartz grains). Samples appeared to be effectively and consistently zeroed, giving a series of well-constrained ages over the period of ~4700–440 years ago, correctly ordered according to stratigraphy and sedimentary geometry. Tidal flat sediments collected from the present-day shoreline returned zero ages within analytical uncertainty (Roberts and Plater, 2005). Madsen et al. (2007a, b) dated fine sand quartz grains (90–180 μm and 180–250 μm) extracted from sediment cores retrieved from salt marshes of the Danish Wadden Sea. The resulting ages enabled the calculation of sedimentation rates which were consistent with the geological estimate. While all these studies used fine sand grains, Mauz and Bungenstock (2007) dated fine-silt quartz grains extracted from mudflat sediments at the German North Sea coast. All but two OSL ages fell into the expected time interval but no independent age control was available for individual samples.

For further information, Jacobs (2008) reviews luminescence dating development and application for coastal and marine sediments.

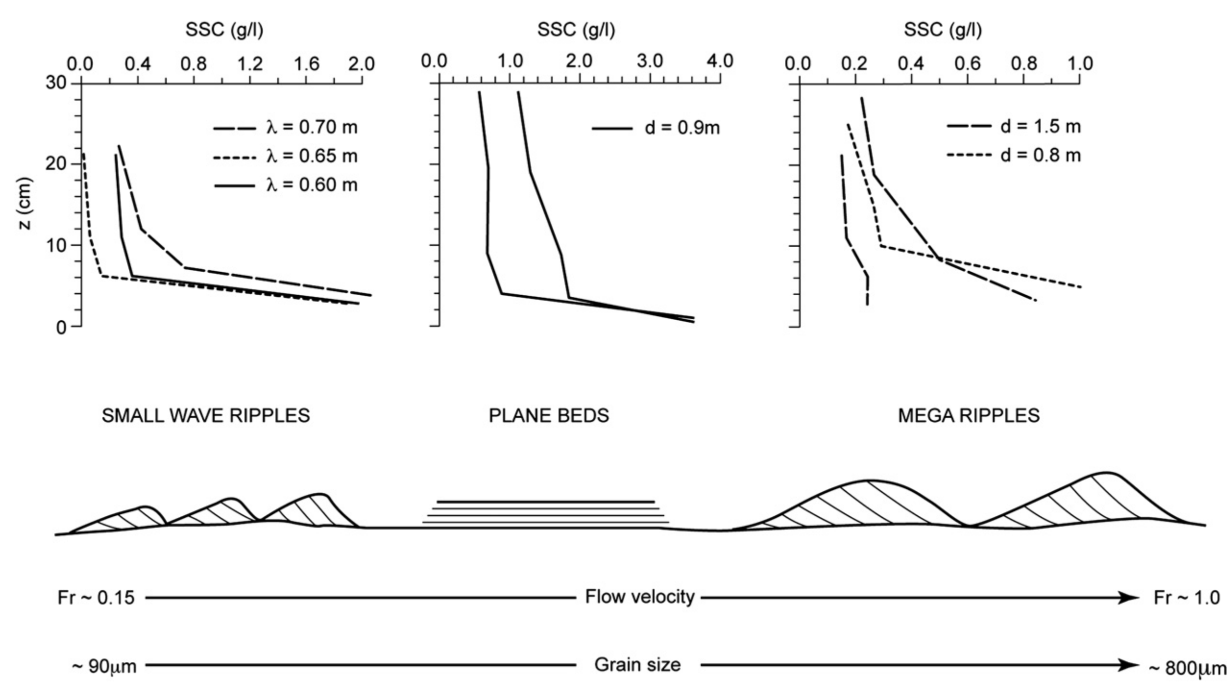

Fig. 1. Simplified illustration of the relationship between flow regime (Froude number, Fr), sediment bed, grain size and suspended sediment concentration (SSC). SSC data are from the SE Australian coast (Nielsen, 1984). Note that this illustration does not account for the lateral change of setting due to e.g. bidirectional flows. λ = wavelength; d = water depth.