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Research paper

Variations in luminescence properties of quartz and feldspar from modern fluvial sediments in three rivers

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ABSTRACT

Studies of modern sediments, their sedimentology and depositional processes are important for understanding the behaviour of the luminescence characteristics of quartz and feldspar in fluvial settings. Previous studies have shown large variations in OSL characteristics of quartz from different fluvial systems, while the IRSL and pIRIR signals from K-feldspar have been understudied. We test the effects of fluvial setting on luminescence characteristics by collecting modern (<1 year old) bedload sediments down the courses of three river systems with very different hydrological characteristics, geologic contexts, and catchment lithologies. The single grain (SG) and multi-grain aliquot (MGA) OSL (quartz) and IRSL and pIRIR (K-feldspar) properties of samples were measured and compared to better understand intra- and inter-fluvial system patterns in sensitivity, bleaching, and equivalent dose (D_e) distribution skewness and kurtosis. The quartz OSL and K-feldspar IRSL and pIRIR signal sensitivities increase with downstream transport distance of sediments, confirming previous studies (quartz) and showing that IRSL signals from K-feldspar also increase in response to reworking cycles. Increasing transport distance also results in better bleaching of the OSL signal from quartz samples (MGA and SG) due to more grains being exposed to sunlight. By contrast, the IRSL and pIRIR signals retain significant residuals in all samples, though 5–15% of grains yield zero-dose D_e values and age modelling of SG data yields accurate burial dose estimates. Additionally, the skewness and kurtosis of SG OSL D_e datasets from one river increase with transport distance, with the best bleached samples exhibiting the highest skewness, thereby questioning the applicability of the skewness-value of a D_e dataset as an accurate indicator for partial-bleaching. Our data shows marked variability between (i) different river systems and (ii) the measured minerals, however consistent use of statistical models allows accurate D_e estimation in all contexts. Age modelling of SG data from K-feldspar, thus, provides a valuable tool for future fluvial research in regions where poor OSL characteristics prevent the use of quartz as a dosimeter.

1. Introduction

Constraining the timing and nature of fluvial aggradation and erosion via optically stimulated luminescence (OSL) and infrared (IR) stimulated luminescence (IRSL) dating techniques enables sedimentologists and Quaternary scientists to tackle tectonic, climatic, and palaeohydrologic questions (Mukul et al., 2007; Thomas et al., 2007; Sawakuchi et al., 2012; Jansen et al., 2013). However, sediments that were transported and deposited by fluvial processes present a suite of problems that complicate the estimation of accurate luminescence burial ages. Since optical-luminescence dating methods are used to provide an estimate of the time elapsed since luminescent minerals (quartz – OSL; K-feldsapr – IRSL) were last exposed to sunlight, a major assumption of this method is that the grains are exposed to sufficient sunlight to bleach their latent luminescence signal (Huntley et al., 1985; Rhodes, 2011). In fluvial settings, incomplete resetting of the latent luminescence signal, due to attenuation of sunlight through a sediment-laden water column and short transport distances during low-light conditions, can be problematic and result in age overestimations (Murray et al., 1995; Olley et al., 1999; Stokes et al., 2001).

One approach for understanding these problems is to investigate the residual luminescence signal in aliquots (single- or multi-

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grain) of sediments from modern floodplains or active channels (Murray et al., 1995; Olley et al., 1999; Stokes et al., 2001; Jain et al., 2004; Singarayer et al., 2005; Fiebig and Preusser, 2007; Alexanderson, 2007; Hu et al., 2010; Alexanderson and Murray, 2012; McGuire and Rhodes, 2015). Two general, though not ubiquitous, observations are evident. Firstly, modern fluvial sediments usually contain some quartz grains that yield near-zero equivalent dose (D_e) values that would be unlikely to result in significant age overestimations for older sediments (e.g., sediments older than 1 ka according to Jain et al., 2004), while K-feldspar grains yield variable results; some studies report small IRSL residuals (McGuire and Rhodes, 2015) and others report significant IRSL and/or pIRIR residuals (Trauerstein et al., 2014; pIRIR in McGuire and Rhodes, 2015). Secondly, bleaching often improves with transport distance, as indicated by decreasing residual D_e values with distance downstream (Stokes et al., 2001; MET-pIRIR signal in McGuire and Rhodes, 2015), though this is not always observed (e.g., Hu et al., 2010; IRSL signal in McGuire and Rhodes, 2015).

A second approach used to investigate, identify and overcome partial bleaching is to measure many individual grains. This approach allows those fully bleached grains to be identified in a population that includes incompletely bleached grains, which will yield overestimates of the true burial age when combined on the same multi-grain aliquot (MGA) (Arnold and Roberts, 2009; Nian et al., 2012). Many researchers have suggested that the combination of completely and incompletely bleached grains will yield positively skewed single grain (SG) D_e distributions (Olley et al., 1999; Bailey and Arnold, 2006; Summa-Nelson and Rittenour, 2012). Statistical models are subsequently used to isolate the grains that were sufficiently bleached (Olley et al., 1998; Galbraith et al., 1999; Lepper et al., 2000; Thomsen et al., 2007), with the assumption that calculating weighted mean D_e values (e.g., with the central age model) will result in similar overestimates as measuring MGAs.

The problems of partial bleaching are magnified when using the IRSL or pIRIR signal from K-feldspar grains, which are less bleachable than the OSL signal from quartz (Godfrey-Smith et al., 1988; Lawson et al., 2012; Colarossi et al., 2015). Because of this and the near ubiquity of anomalous fading of the IRSL signal in K-feldspars (Spooner, 1994; Huntley and Lamothe, 2001), the quartz-OSL signal from fluvial sediments has been the preferred luminescence dosimeter and received more thorough investigation. However, many regions and geomorphic contexts (e.g., alpine and tectonically active settings) lack sensitive quartz grains but have quite sensitive K-feldspar grains (Preusser et al., 2006; Fuchs et al., 2013; Rhodes, 2015). Recent advances have identified low- or non-fading signals (e.g., pIRIR signals – Thomsen et al., 2008), which are unfortunately more difficult to bleach (Lowick et al., 2012). This necessitates the use of K-feldspar to address research questions and, thus, a better understanding of the behaviour of the IRSL and pIRIR signals of fluvially transported K-feldspar grains is needed to ensure the use of optimal measurement and data analysis procedures to obtain accurate burial ages (Rhodes, 2015).

This study aims to address three specific questions. Firstly, how do OSL/IRSL/pIRIR characteristics (e.g., residual De/bleaching, luminescence sensitivity, SG D_e distribution skewness and kurtosis) change with transport distance in a given fluvial system? Secondly, do different fluvial systems with varying hydrologic characteristics yield different luminescence characteristics? Thirdly, what measurement and data analysis procedures yield the most robust IRSL and pIRIR ages? These aims were approached by collecting modern (<1 year old) bedload sediments along three river systems with very different hydrological characteristics, geologic contexts, and catchment lithologies: Cooper Creek (arid central Australia), Wollombi Brook (temperate eastern Australia), and the Pitze River (European eastern Alps). The chosen rivers represent end-members of a litho-luminescence spectrum; the Australian rivers carry bedload that is quartz rich with well-behaved OSL signals and no K-feldspars while the alpine Pitze River transports insensitive quartz and K-feldspar with bright IRSL and pIRIR signals. The SG and MGA OSL (quartz) and the SG and MGA IRSL and pIRIR (K-feldspar) properties of samples were measured and compared to better understand intra- and inter-fluvial system patterns in sensitivity, bleaching, and D_e distribution skewness and kurtosis. The variability in the observed patterns is discussed along with possible explanations and implications.

2. Experimental procedures and sampling sites

To address the aims of this study 17 samples were collected from fluvial bedforms (channel bars) that were less than one year old at the time of sampling at different locations down the long profile of three different rivers (Fig. 1). The mode of deposition is known and only samples with clearly observable bedding features were used in this study, thus guaranteeing that post-depositional mixing could not have affected the D_e distributions. Likewise, since the age of each deposit is known to be very young, any spatial heterogeneity in the dose rate of the current depositional setting will not have had time to affect D_e distributions, although unbleached grains may retain the inherited effects of heterogeneous dose rates of their previous depositional setting. Consequently, any grains that yield non-zero D_e values must have been incompletely bleached during the last episode of fluvial transport; their residual doses could reflect (i) unbleached dose remaining after exhumation from bedrock or (ii) a burial dose acquired during storage in the floodplain before the most recent fluvial transport event. Two of the rivers (Cooper Creek and Wollombi Brook) are in Australia and have no K-feldspar, but do have quartz with a bright OSL signal that is dominated by the fast component (Table 1). The third river (the Pitze River) is located in the Austrian Alps and drains a catchment with insensitive quartz but bright K-feldspar with minimal fading (see discussion below and Table 2). Single grains of quartz (Australian rivers) and K-feldspar (Pitze River) were measured in addition to large multi-grain aliquots.

Cooper Creek and Wollombi Brook are both ephemeral rivers that have very different hydrographic characteristics, catchment sizes, and lengths (Figs. 1 and 2). Cooper Creek is an order of magnitude longer than Wollombi Brook, has a catchment area that is two orders of magnitude larger (>300,000 km^2 vs 1,848 km^2) and has a flow hydrograph period that is an order of magnitude longer (weeks vs hours). Cooper Creek is a low gradient (200 mm/km) multi-channel river system flowing from the seasonally wet tropics and sub-tropics into the arid interior of the Australian continent. It passes through synclinal basins which store sediment in subsiding 50 km wide floodplains for 10^5–10^6 years (Nanson et al., 2008; Jansen et al., 2013) and through linear dunefields of Australia's central desert. A long history of Late Palaeocene–Early Eocene basin sedimentation through to the present characterises the sedimentary setting with various sediment sinks, provenances and interactions of fluvial, aeolian, and lacustrine processes (Habeck-Fardy and Nanson, 2014). Hydrographs on the Cooper Creek are extended and often last for months (Fig. 2a). By contrast, Wollombi Brook is a river channel <100 km in length in a confined valley (often < 1 km wide) that cuts through a catchment dominated by a single lithology (Triassic sandstones; Rasmus et al., 1969) with sedimentation limited to small Holocene terraces (Erskine and Melville, 2008). There are no significant sediment sinks, and once exhumed from bedrock, grains will be transported down the length of the river during the infrequent flow events. Peak discharges in this sand bed system are rainfall-driven and tend to last for <12 h