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Research Paper

Fluvial transport as a natural luminescence sensitiser of quartz

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Abstract

The optically stimulated luminescence (OSL) sensitivity of quartz sampled from the bed of the Castlereagh River in inland New South Wales increases linearly with distance downstream, through both a proportional increase in the number of luminescent grains and increases in the sensitivity of individual grains. It is argued that downstream transport provides numerous opportunities for repeated irradiation and bleaching which combine to increase sensitivity of the quartz grains. Individual quartz grains collected from the uppermost sampling site on the Castlereagh River increase in sensitivity in response to repeated cycles of laboratory irradiation, heating and illumination, providing an explanatory analogue. Furthermore, initially non-luminescent grains are shown to be 'switched on' by this same laboratory treatment. We conclude that downstream increases in the luminescence sensitivity of quartz observed in the Castlereagh River are due to intrinsic changes within the quartz and not due to any macro changes in the grains, for example polishing, or abrasion and loss of non-luminescent grains. We also infer that the high OSL sensitivity of sedimentary quartz from Australia is due to the predominance of environments which provide numerous opportunities for repeated irradiation, illumination and heating. Observation of the change in luminescence sensitivity of quartz bedload has the potential to provide additional information on the nature of bedload transport processes. Data from the Castlereagh River indicate that the rate of bedload transport is approximately constant along the ~325 km sampled reach.

Keywords: OSL; Single grain; Sensitivity; Bedload transport; Castlereagh river; Australia

1. Introduction

The optically stimulated luminescence (OSL) of quartz grains arising from radiation exposure has been widely used for dosimetry and dating (e.g. Aitken, 1998). In sedimentary dating, a depositional age is calculated by comparing the radiation dose acquired since burial, as measured using the OSL signal, with the dose rate, derived primarily from the surrounding sediment. The intensity of the OSL signal from a quartz grain is a function of the size of the total radiation exposure to which it has been exposed since burial, as well as the efficiency with which this radiation dose is expressed as emitted photons during the measurement process. In this paper we examine how this efficiency, or sensitivity, changes in quartz samples from the Castlereagh River, Australia, particularly in relation to transport distance.

This work arose from the generally observed high luminescence sensitivity of Australian sedimentary quartz. A typical sample of Australian quartz may be orders of magnitude brighter (that is, more sensitive) than an equivalent sample from, for example, Europe (e.g. Klasen et al., 2006) or the Pacific islands (Fig. 1). This high luminescence sensitivity can be found in samples derived from a diverse range of bedrocks, supporting the suggestion of Preusser et al. (2006) that luminescence sensitivity is not directly related to rock type, or at least not this alone. The highly sensitive nature of Australian quartz means that very small doses (<20 mGy) can be measured from single grains, obviating the need to use large aliquots for the measurement of very young ages (e.g. Ballarini et al., 2003; Madsen et al., 2005), and thus making the single-grain dating of very young (<100 years) heterogeneously

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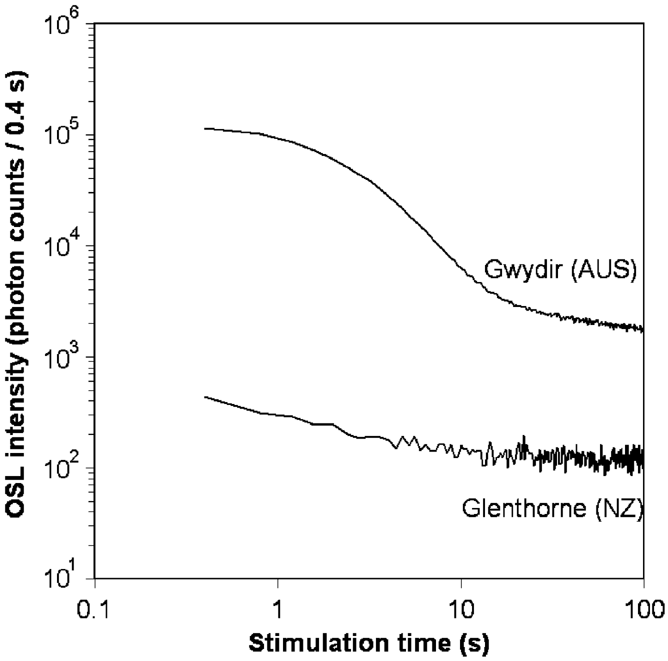

Fig. 1. Comparison of OSL decay curves of floodplain samples from Australia and New Zealand. Both decay curves are from 5 mm diameter aliquots of quartz, in response to ~5 Gy β irradiation.

bleached Australian fluvial samples now routine (e.g. Rustomji and Pietsch, 2007).

It may be assumed that quartz sensitivity is due to high charge (electrons and electron holes) traffic between electron traps and luminescence centres (L-centres) with the most obvious determinant of the rate and/or quantity of this traffic being the absolute number of traps and L-centres (McKeever, 1985; Hashimoto et al., 1994, 1997; Vartanian et al., 2000) with this number being determined largely by crystal formation conditions. Moreover, most luminescence models (e.g. Zimmerman, 1971; McKeever, 1991; Bailey, 2001; Itoh et al., 2002) include competitor traps which are not subsequently sampled in the measurement process, and non-luminescent, phonon-producing centres (R-centres). R-centres compete with L-centres for free charge. The degree to which this competition from R-centres disrupts the flow of charge traffic between electron traps and L-centres will be as important as the absolute number of traps and L-centres in determining luminescence sensitivity. It may be posited then, that the Australian quartz so far sampled must be peculiarly endowed with high numbers of traps and/or L-centres, or alternatively, the level of disruption of charge traffic by R-centres must be comparatively low. While relatively little research has been directed towards quantifying the number of luminescence traps and centres in natural quartz, an extensive body of work exists recounting investigations into the effects of various laboratory treatments on the competitiveness of L-centres compared to R-centres. Heating (e.g. Aitken and Smith, 1988; Bøtter-Jensen et al., 1995; Rhodes and Bailey, 1997; Rhodes, 2000; Wintle and Murray 2000; Bailey, 2001); bleaching (Wintle, 1985; Bowall et al., 1987; McKeever, 1991; Li and Wintle, 1991, 1992; Morris and McKeever, 1993; Stokes, 1994; Zhou and Wintle, 1994) and irradiation (e.g. Zimmerman, 1971; Durrani et al., 1977; Stoneham and Stokes, 1991; Bailiff, 1994; Chawla et al., 1998; Benny et al., 2000) have all been shown to change the sensitivity of quartz, presumably by altering the proportional capture of charge between L-centres and R-centres. Suggested mechanisms which may determine this proportion include the thermal transfer of holes from shallow R-centres to thermally stable L-centres (Zimmerman, 1971); recombination at L-centres during irradiation (Aitken, 1985); an increase in competitiveness of the R-centres during irradiation and heating (Bailey, 2001); or the irreversible thermal conversion of R-centres to L-centres (Vartanian et al., 2000).

Although there may be some mineralogical peculiarity of Australian quartz, such that high concentrations of defects relevant to the luminescence pathway are common, the unusual sensitivity of Australian quartz is likely, at least in part, to be a result of environmental conditions experienced by quartz within the Australian landscape. Just as the laboratory treatments outlined above alter the sensitivity of quartz, so too must their natural analogues. Very little research has been done in this area. Li and Wintle (1991, 1992) suggested that colluvial samples should be distinguishable from aeolian samples based on differential sensitisation occurring during their final, pre-burial bleach (i.e. colluvial = short bleach resulting in low sensitivity; aeolian = long bleach resulting in high sensitivity). Wintle and Murray (1999, 2000) make a passing reference to the ambient temperatures experienced by Australian quartz, commenting that old Australian samples could be thermally sensitised by long storage at relatively high environmental temperatures. These studies suggest a link between components of the environmental history of a sample and its final sensitivity, however, if ambient temperature or bleaching severity alone were the sole determinants of sensitivity it could be expected that sensitivity would be inversely related to latitude. Such a relationship has not been documented, and equatorial samples with which the authors are familiar are generally very insensitive. It is here proposed that rather than any of the individual 'natural' treatments causing Australian quartz to be highly sensitive, it is instead the effect of all of such treatments in combination. We hypothesise that Australian quartz is particularly sensitive because of the number of cycles of irradiation, bleaching and heating it experiences during weathering from bedrock and transportation to its site of sampling. Repetitive natural processes operate in much the same way as repetitive laboratory treatments, sensitising the quartz to subsequent irradiation and measurement. To test this hypothesis we have collected nine surface bed sediment samples from the bed of the Castlereagh River (Fig. 2), which for the purposes of this study has an ideal ephemeral flow regime and uncomplicated geology