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A comparison of natural- and laboratory-generated dose response curves for quartz optically stimulated luminescence signals from Chinese Loess

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HIGHLIGHTS

► Natural dose response curves can be made from profiles with independent age control.
► Natural- and laboratory-generated dose response curves differ in shape.
► Laboratory-generated dose response curves grow at higher doses than natural curves.
► Component fitting and multiple aliquot protocols cannot resolve these differences.
► These differences result in age underestimation above 150 Gy at Luochuan, China.

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ABSTRACT

It has previously been observed that laboratory-generated quartz optically stimulated luminescence (OSL) signals from different samples have similar dose response curves (DRCs) after they are normalized using a test dose. It therefore seems likely that growth of the normalized signal due to natural irradiation of quartz may also follow a general dose response curve. The existence of such a curve is investigated by constructing a natural DRC from the test dose-normalized natural OSL signals of seven samples from the Luochuan section of the Chinese Loess Plateau. The same aliquots are then used to build single aliquot regenerative (SAR) DRCs, making it possible to compare the natural and laboratory constructed curves. Two main differences are observed. Firstly, the laboratory-generated DRCs are best fitted with double saturating exponential functions whereas the natural DRC is equally well fitted with a single saturating function. Secondly, in the laboratory-generated DRCs the normalized OSL signal continues to increase at high laboratory doses (>500 Gy), whereas no growth is seen at these doses in the equivalent natural DRC. These differences between natural- and laboratory-generated DRCs are still apparent even if data are manipulated to isolate the fast component, or if a sensitivity corrected multiple aliquot regenerative (SC-MAR) dose procedure is used. This suggests that the observed differences are not due to the influence of different components or inter-regenerative dose cycle sensitivity changes. The divergence between the natural- and laboratory-generated DRC means that the current maximum limit of quartz OSL dating at the Luochuan section is 150 Gy, as D_e estimates above this value are likely to be underestimations.

1. Introduction

Investigations into standardized growth curves for the optically stimulated luminescence (OSL) signal from quartz have demonstrated that similar dose response curves (DRCs) can be built in the laboratory for samples collected in different regions and sedimentary environments when aliquots are normalized with a sensitivity correcting test dose (Roberts and Duller, 2004). This idea has been applied in the use of common growth curves, based on similar DRCs from samples within the same study area, for determining equivalent doses for multi-grain aliquots (Lai et al., 2007; Lai, 2006; Stevens et al., 2007). The similarity in average behaviour observed between laboratory-constructed dose response curves from different samples opens up the possibility of the existence of a natural dose response curve, where growth of the normalized OSL signal from quartz due to natural irradiation over geological time follows a general dose response curve. If such

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a natural DRC exists, it would enable unprecedented comparison between OSL signal growth with radiation exposure in the laboratory and in nature, thereby enabling validation of the basic assumption of OSL dating; namely, that OSL signal growth due to beta irradiation in the laboratory is the same as that due to a lower intensity, mixed radiation field in nature. Furthermore, comparison of laboratory and natural dose response curves could provide a means of testing new techniques and protocols as luminescence techniques advance.

In order to create a natural DRC, it is necessary to find a field site to act as a natural laboratory, i.e. where sediment has been accumulating for at least as long as it takes the environmental dose rate to saturate the quartz OSL signal. For multiple grain aliquots, it is necessary for all grains throughout the deposit to have had sufficient sunlight exposure to fully deplete the OSL signal before burial. It would be advantageous for the sediment to be homogenous and have similar source material so that luminescence sensitivity and environmental dose rates vary minimally throughout the deposit. Finally, it is essential that there exist some framework of independent age control that can be used to estimate the expected equivalent dose for each sample collected.

One location that meets all of these criteria is the Chinese Loess Plateau. Wind-blown dust has accumulated in central China almost continuously for the past 2.6 million years (Liu, 1985), at least an order of magnitude longer than can be accurately dated with OSL in areas of reasonably high environmental dose rate. The dust originates from the deserts and desert margins north of the Plateau and becomes mixed and bleached during transport (Ding et al., 2002). Palaeosols formed in the loess deposits have been correlated with oxygen isotope records from marine cores and patterns of orbital cyclicity (Ding et al., 2002; Liu, 1985; Liu and Chang, 1964) providing a framework of independent age control that is visible in the field throughout the Chinese Loess Plateau. Some studies have demonstrated that quartz OSL from different loess units within a single site have reproducible DRCs (Stevens et al., 2007) and others (e.g. Lai, 2006; Roberts and Duller, 2004) have suggested that the growth curves are reproducible even between sites.

The Luochuan section near the centre of the plateau has often been regarded as a type section (Liu, 1985). The stratigraphic profile at this section is nearly 130 m thick and fully exposed from the modern agricultural soil to the 2.6 Ma loess-red clay boundary (Kukla and An, 1989). Previous luminescence dating studies at this section have not only investigated the palaeoclimatic record, but also tested many new protocols against the framework of independent age control provided by the loess-palaeosol sequences. Several of the protocols tested have been successful for the uppermost loess (Forman, 1991; Lai, 2009; Lai et al., 2006; Lu et al., 2007; Wang et al., 2006) but others have reported age underestimations and other complications (Buylaert et al., 2007; Lai, 2009). Buylaert et al. (2007) observed age underestimation at the marine isotope stage (MIS) 4/5 boundary and therefore suggested that the maximum age limit of quartz OSL at Luochuan is about 40–50 ka, which corresponds to a maximum equivalent dose of about 120–150 Gy. Lai (2009) also reported age underestimation compared to the loess-palaeosol sequences, his DRCs were best fitted with saturating exponential plus linear functions and the additional linear component was not reliable in producing accurate equivalent dose estimates above 230 Gy.

This paper investigates the existence of a natural dose response curve at the Luochuan loess section and compares it to laboratory constructed dose response curves from the same material in order to test the similarity between the natural and laboratory-constructed curves. The paper then goes on to investigate the maximum limit of OSL dating at this site.

2. Equipment and sample preparation

Seven samples from the Luochuan section were used in this study (Fig. 1). All of the samples were collected from loess units in order to avoid post-depositional mixing and changes in environmental dose rate due to soil formation processes (Bateman et al., 2003). Six of the samples were taken within 60 cm of a palaeosol-loess boundary in order to minimize the distance from tie points with the framework of independent age control. The other sample was collected 2.0 m into the L1 loess and provides additional data in the conventional OSL age range. The samples were collected as small blocks wrapped in black plastic. Once they were in the darkroom conditions of the laboratory, exteriors of the blocks were removed and separated for dose rate calculations. The remaining material was treated with 10% volume to volume dilution of concentrated HCl and 20 vols H_2O_2 until no continued reaction could be identified. They were sieved to 35–63 μm, treated with H_2SiF_6 for 14 days to remove feldspar, and subsequently re-sieved as a further quartz purification step.

Environmental dose rates were measured using the material that had been removed from the exterior of the blocks. This material was pulverised and homogenized before being measured using thick source alpha and beta counting. The modern water content was measured for each sample and gave an average value of 5 ± 3%. As this value is likely to be lower than the average water content during burial because of desiccation from cliff-face exposure, the average burial water content was assumed to be 10 ± 5%

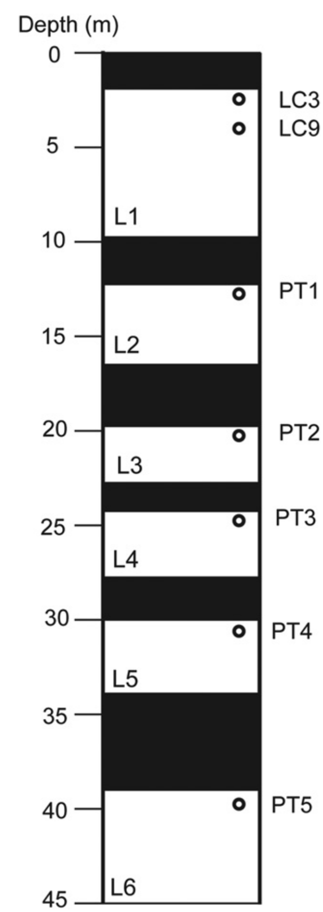

Fig. 1. Pedostratigraphy of the uppermost 45 m of the Luochuan loess section demonstrating the location of OSL samples used for this study taken from loess units L1–L6. Paleosols are shown in black and unshaded regions are loess.