LUMINESCENCE OF SINGLE QUARTZ GRAINS TO DETERMINE PAST MOVEMENT AND HEATING

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INTRODUCTION

Sand grains can enter the regolith from below by the weathering of bedrock, from above by aeolian processes or from across the earth's surface by a wide range of fluvial and slope processes. They may also be translocated laterally and vertically within the regolith by physical or biological agencies. The magnitude and rate of these processes are very important in controlling the creation and evolution of regolith, and have been the subject of detailed studies using cosmogenic isotope production and changes in the Optically Stimulated Luminescence (OSL) signal (Heimsath *et al*. 2000, 2002, Rhodes *et al.* 2003).

One of the key parameters used in Heimsath *et al*. (2002) to estimate the rate of soil turnover was the proportion of grains which produced no measurable OSL signal. This behaviour was assumed to be present only for grains which had not yet been exposed to surface processes including light exposure and heating in bushfires.

Quartz Thermo-Luminescence (TL) sensitivity has long been observed to increase on heating, and OSL sensitivity was observed to vary in a similar manner (Smith *et al*. 1986, Rhodes 1990, Stoneham & Stokes 1991, Wintle & Murray 1999). The increase in TL sensitivity of the 110ºC TL peak was also found to be approximately proportional to previously administered radiation dose (referred to as pre-dose) for a given heat treatment, and this formed the basis of a convenient dating method for young samples such as archaeological ceramics (Aitken 1985). Several different methods have been applied for this TL "pre-dose" dating technique, the success of each apparently being related to the characteristics of each individual sample.

In this abstract, we present measurements of TL sensitivity changes of multi-grain and single grain aliquots of sand-sized quartz from a surface soil sample collected from near Sheehys Creek, Lake Burragorang Catchment, NSW. These preliminary studies were undertaken in order to assess the feasibility of using the observed TL changes to determine the timing and magnitude of past bushfire events. However, they are also useful in developing our understanding of the wider phenomenon of quartz luminescence sensitivity change, and its relationship to a range of different factors including the provenance and geochemical conditions of crystallization, and events in the history of each grain such as deep burial and geothermal heating, massive natural dose exposure over millions of years, surface exposure to daylight and heating events and interaction with near-surface geochemical systems. We provide some interesting observations and speculative preliminary interpretations of the data, as an introduction to the huge potential that this approach offers for resolving these events in the future.

LUMINESCENCE SENSITIVITY CHANGE ON HEATING

Luminescence sensitivity is defined as the light output in response to a given radiation dose when the sample is subsequently heated in the case of TL, or exposed to a stimulating light source in the case of OSL. For many natural quartz samples, the TL and OSL sensitivities are observed to increase following laboratory heating. In TL, sensitivity change of different TL peaks may be independent, as described for the 330ºC and 375ºC TL peaks in a sample of Cothill quartz by Rhodes (1990).

A formalised approach to the measurement of this phenomenon is provided by the thermal heating characteristic, or TAC (Aitken 1985). The most convenient TL peak to use for assessing changes in quartz TL sensitivity is the peak observed around 110ºC after laboratory dosing. Electrons in this shallow trap have a relatively short lifetime at room temperature of around 1 hour, and a relatively low temperature is required for its measurement. Hence, in natural samples this trap has no initial charge populations, and sensitivity measurements can be made by heating to around only 160ºC after a small beta dose has been given. During TL measurement, electrons may recombine by the emission of phonons (thermal energy) in place of photons (the TL signal), causing an effect referred to as thermal quenching (Wintle 1975). This effect increases at higher temperatures in quartz, but is very low for the 110ºC peak, leading to a high effective sensitivity, and the requirement to use only small laboratory doses for sensitivity change determination. A further advantage of this signal is that similar peaks are generally not observed in other minerals. These factors lead to the 110ºC TL signal representing an excellent tool for the study and quantification of luminescence sensitivity change.

Many samples also display an initial decrease in sensitivity of the 110ºC TL and the OSL after laboratory dosing, which is not observed for higher temperature TL peaks. This phenomenon is referred to as dose quenching. It is understood not to be present for higher temperature TL peaks because these signals cannot (by definition) be measured except by heating the sample, causing the usual rise in sensitivity to occur as the measurement is made. Luminescence sensitivity change is a function of at least 4 main factors, namely: i) the concentration of target electron traps available during dosing; ii) the magnitude of charge competition from other electron traps and hole centres during dosing; iii) the concentration of luminescence centres with appropriate emission characteristics available during luminescence measurement; and, iv) the magnitude of charge competition from other electron traps and hole centres during luminescence measurement. Changes in TL or OSL sensitivity have usually been considered in terms of changes in iii) or iv) above, though mechanisms i) and ii) may also be at least partly responsible. It should be noted that other effects, such as the opacity of the grain may also change TL or OSL sensitivity.

Given this degree of complexity, and observed variations in sensitization even of sub-grains of the same single quartz crystal (Adamiec 2000), we do not attempt to suggest detailed mechanisms for the processes involved in sensitization. However, we note that the movement of electrons or ions within the crystal lattice as a result of dose, light exposure or heating represent the most likely causes of sensitivity change (Aitken 1985, Adamiec 2000).

PRELIMINARY EXPERIMENTAL RESULTS

Eight sub-samples of the surface soil sample (0 to 2.5cm depth) were heated to different temperatures in the range 50 to 800ºC for 40 minutes. Sand-sized quartz grains were separated from the bulk sediment of each sub-sample using standard procedures, and several aliquots of around 500 grains were prepared. These were divided into two groups, and TAC measurements performed. One group was measured directly, while the second group was given a 10 Gy beta dose (to simulate burial after burning), and three aliquots measured for each TAC. Results are shown in Figure 1. The sub-samples all displayed rather modest sensitization, with a maximum increase of less than a factor of 3, even on heating to 800ºC. It is noted that the sub-samples that display the least change are those previously heated to 600ºC, for both raw and dosed samples.

In order to assess the variability of TL sensitization between individual grains, singe grains from the sub-sample previously heated to 50ºC for 40 minutes were mounted. This sample acts as a proxy for an unheated sample, which was not available. 60 single grain samples were measured, and a selection of typical TAC plots is shown in Figure 2. A wide range of behaviours and initial sensitivities was encountered.

DISCUSSION AND CONCLUSIONS

Comparison of the single grain TAC plots to those measured for sub-samples of the same material previously heated to different temperatures may assist in the interpretation of the results shown in Figure 2. However, we note that the past thermal history of this sample before collection remains unknown, and we plan to measure grains from a bedrock sample of similar geological provenance which is known to be unheated by bushfires as a control sample. However, it is tempting to attempt a simplistic interpretation of the single grain results based on a comparison of the TAC forms with those of the multigrain sub-samples (Figure 1). Each single grain TAC has been allocated a suggested heating value and prior dose simply by selecting the multigrain TAC most similar in form (though not in magnitude). These results suggest that many single grains may have been heated to temperatures ranging from 400 to 800ºC, illustrated by the histogram in Figure 3. Very few samples (17%) display characteristics associated with receiving significant dose since heating, and a very approximate estimate of the magnitude suggests that maximum ages since heating for these grains may be 10,000 to 15,000 years.

We cannot yet make firm conclusions regarding the past thermal history of individual grains from this sample. We have not measured grains from a similar but definitively unheated source, and the details of the mechanisms involved in luminescence sensitivity change remain unexplained. However, we plan to develop this method further, as it clearly displays excellent potential for recovering information concerning the intensity and timing of past bushfire events. Developing a better understanding of the process of sensitization will also assist in our future studies of soil mixing processes and regolith development by biological and physical mechanisms.

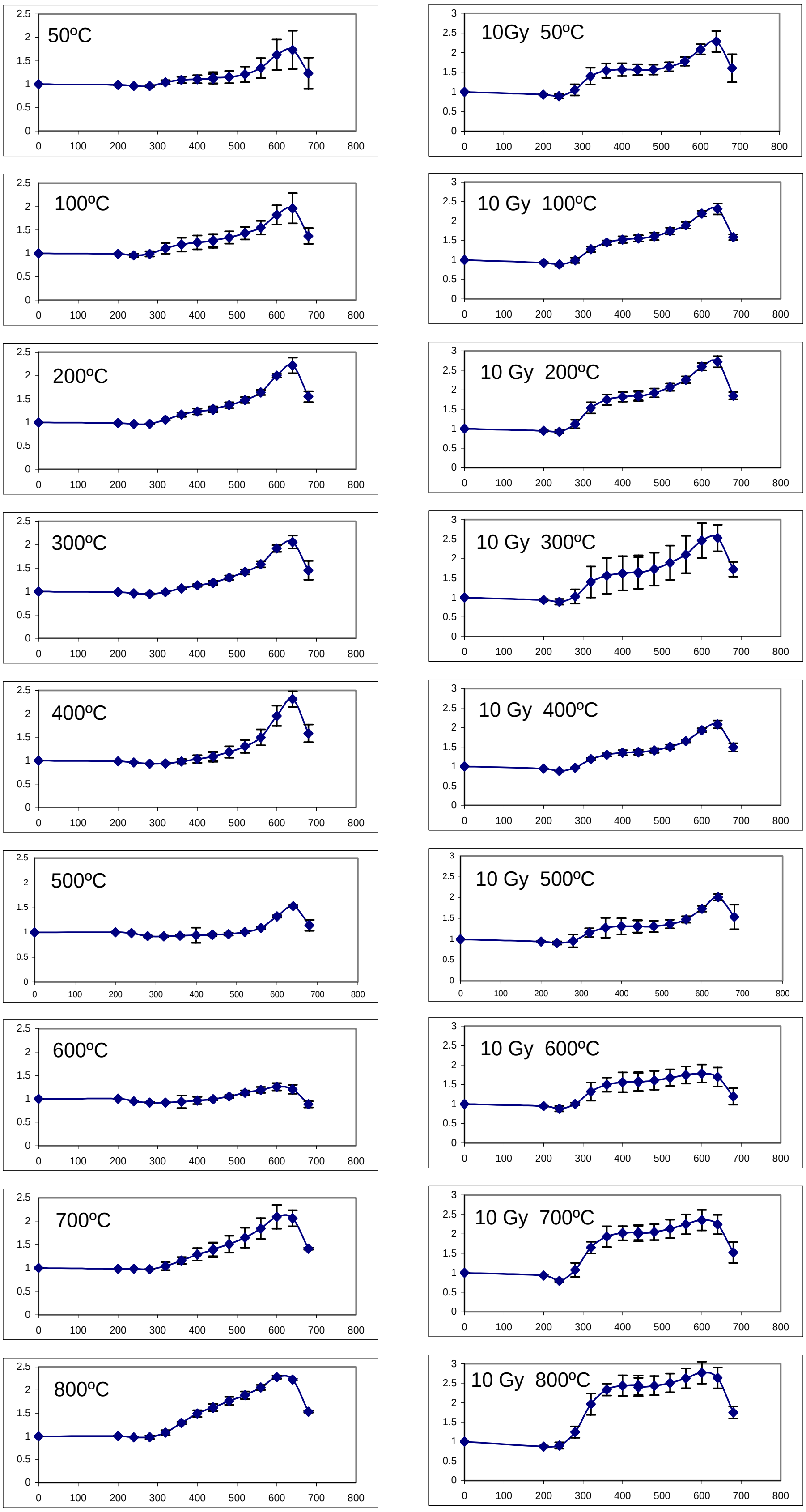

Figure 1: Thermal Activation Characteristics (TACs) for multigrain sub-samples. Each plot shows the ratio of sensitivity after heating to the temperature shown on the bottom axis to initial sensitivity. Legend shows prior laboratory dose and heating treatments. Prior heating treatments were for 40 minutes in air before separation of quartz grains from soil. Each plot represents the mean of 3 aliquots, errors show one standard deviation. Note differences in y axis scales.

We are currently engaged in studies of regolith mixing processes in the Atherton Tableland, QLD, and around Miling, WA, using single grains of quartz and following the procedures developed by Heimsath et al. (2002) and described by Rhodes et al. (2003). We envisage that luminescence techniques, both TL and OSL, coupled to cosmogenic nuclide concentration determinations and geochemical measurements will provide a significantly enhanced picture of the timing, mechanisms and rates of regolith formation and development.

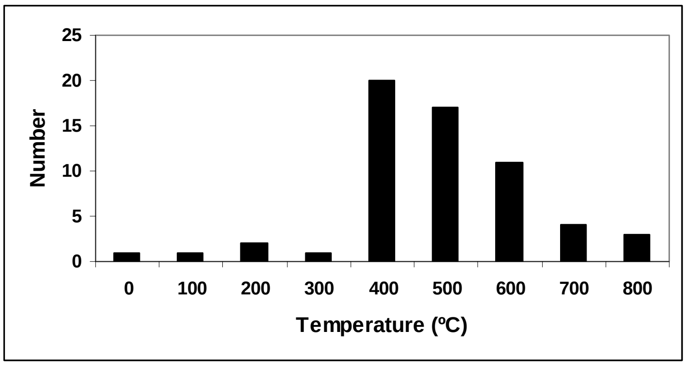

Figure 3: Histogram of inferred possible heating of 60 single grains, using simple comparison of the TAC shape of each to the multi-grain TAC plots shown in Figure 1. Note that this interpretation is high speculative at this stage.

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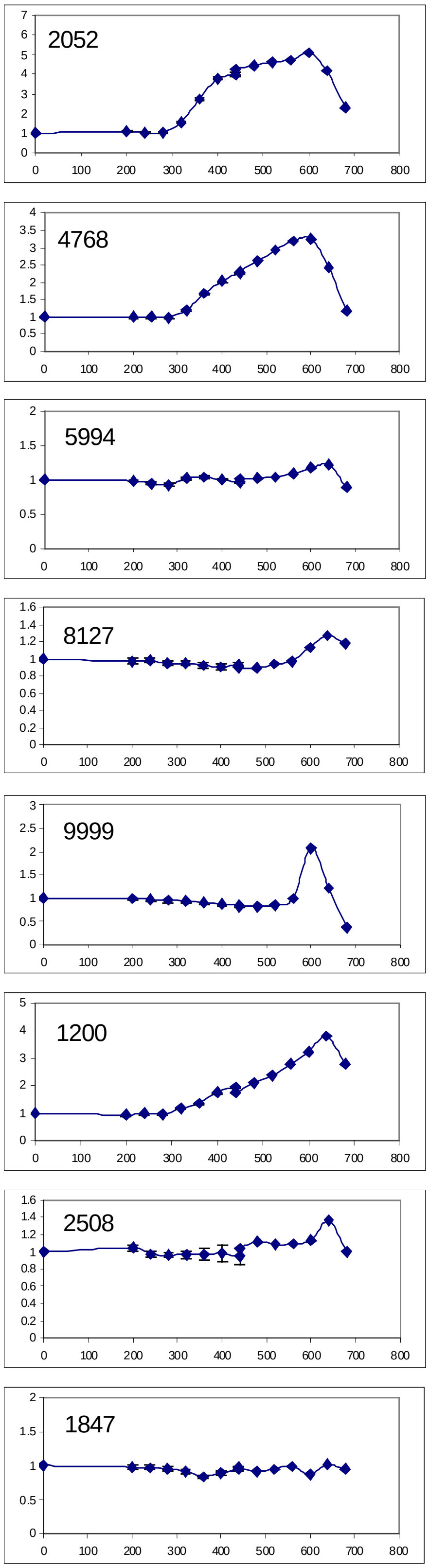

Figure 2: Thermal Activation Characteristics (TACs) for a selection of 8 single grain sub-samples, of 60 measured. All were from the sub-sample previously heated at 50ºC for 40 minutes. Note very different y axis scales. Legend shows initial sensitivity integral counts.