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Application of pulsed optically stimulated luminescence from surface soil to retrospective dosimetry

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HIGHLIGHTS

- A novel P-OSL instrument was developed.
- The performance of the instrument was tested using natural quartz and feldspar.
- An irradiated soil sample was used in a dose recovery test.
- The estimated dose agreed with the expected dose.

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ABSTRACT

A novel pulsed optically stimulated luminescence (P-OSL) instrument was developed. The performance of the instrument was tested using natural quartz extracted from Japanese surface soil and feldspar in mineral specimens. The different P-OSL signals for quartz and feldspar were detected from their decay shape. It was found that the signal from feldspar decayed for 2–3 μs and the signal from quartz was measured at over 50 μs after the LED stimulation was switched off. By using a mixture of quartz and feldspar, the P-OSL protocol was improved to determine the irradiation dose. After irradiating a soil sample, a dose recovery test was conducted and the P-OSL protocol was found to be successful in reconstructing the irradiated dose with an on-time pulse of 4 and 10 μs for quartz and feldspar, respectively. Finally, a soil sample illuminated by a solar simulator was irradiated by a gamma source and then was used in the dose recovery test. The estimated dose agreed with the expected dose. From these results, it can be concluded that P-OSL dosimetry is suitable for the evaluation of the effects of a radiation accident, although further research using actual Japanese surface soil is required to improve the protocol.

1. Introduction

It is difficult to measure a dose received by a building in an unknown place in the event of a radiation accident because a dosimeter would not have been set up in advance. Radiation-induced luminescence such as optically stimulated luminescence (OSL), etc. has been used in the dosimetry of natural quartz and feldspar (Murray and Wintle, 2000, 2002). However, for dosimetry to be effective there is a need to extract the target material from the soil by chemical separation which takes two or three days at least. Particularly, for continuous stimulation OSL (CW-OSL) dosimetry using light-emitting diodes (LEDs) as a source of light stimulation, quartz needs to be completely separated from other materials because the signal from quartz is lower than that from feldspar.

On the other hand, pulsed OSL (P-OSL) has been applied to a dating which could distinguish the OSL signals of quartz from other signals without the need for physical purification of quartz (Thomsen et al., 2008; Ankjærgaard et al., 2010). In P-OSL the stimulation light is delivered in discrete pulses and the emitted luminescence is measured between these pulses. The majority of P-OSL signals from feldspar decays faster than that from quartz. Therefore, it may be possible to isolate quartz OSL signals from a mixed quartz/feldspar sample by considering the difference in their decay times. If it was found to be an effective approach, P-OSL dosimetry could be used in the dose measurement of buildings and the external environment by testing the surrounding soil.

In this paper, a novel P-OSL measurement system is described whose performance was tested on surface soil and a mineral specimen. The measurement conditions were adjusted and used in a dose recovery test by irradiating a sample of surface soil with a standard gamma-ray source.

2. Experimental

2.1. Instrumentation

P-OSL measurements of the samples were carried out by using a JREC automated TL/OSL-reader system (Fujita, 2008) with an integrated pulsing option for the LED stimulation and a photon timer

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attachment with a detection resolution of 1 μs to record the P-OSL (Zcosmos Co., Ltd., HTS2). The stimulation was performed with a 470-nm LED array (Nichia, 470 ± 20 nm; ~12 mW cm^{-2}). Two filters, a Schott UG-11 and a Kenko IRC-65L, were inserted between a sample and a photomultiplier tube (Hamamatsu Photonics, R585S). An in-built X-ray source (Varian, VF-50J tube) with a dose rate of 0.06 Gy s^{-1} to quartz was used for dose delivery to the sample.

We defined the width of each stimulation pulse as "on-time" and the interval of each pulse as the "interval". The lengths of the on-time pulse were set to 1, 2, 4, and 10 μs. The intervals were set to 200, 400 and 800 μs. The total number of stimulation pulses depended on the interval. However, the interval of 200 μs was only tested to determine the P-OSL dosimetry because the P-OSL signals almost disappeared during periods shorter than 200 μs. In other words, the other intervals were not tested in this research. On the other hand, CW-OSL measurements were carried out by using the TL/OSL-reader system without the P-OSL unit.

2.2. Samples

A surface soil sample, which was andosol, was collected from a depth of 0–50 mm in the precinct of a shrine in Ibaraki Prefecture in Japan. Quartz was extracted from this soil sample by chemical separation using 6 M HCl, 6 M NaOH and then 46% HF for 1 h. Further purification of the quartz grains was performed manually to eliminate feldspar grains as much as possible. After sieving < 2 mm particles, the extracted quartz was utilized to determine the P-OSL measurement condition.

To study the tendency of P-OSL, an albite and a plagioclase porphyry were selected as representative types of feldspar from rock specimens.

The soil was illuminated for 2 h by a solar simulator (Seric Co., XC-100) to erase the OSL components caused by the effect of natural radiation. It was confirmed that 2 h of illumination could erase the OSL components. Then the illuminated soil was irradiated to 4.3 Gy with a ^{60}Co gamma-ray source at Kyoto University Research Reactor Institute (KURRI). After irradiation, the sample was cleaned by using a simple chemical procedure with water, 6 M HCl and 6 M NaOH, which took only approximately 2 or 3 h. All preparations were carried out under a dim red light to avoid optical-bleaching effects.

3. Results and discussion

3.1. P-OSL measurement

Before the P-OSL measurements of the samples were taken, CW-OSL decay curves were obtained from quartz and albite, but not from the plagioclase porphyry which did not show a P-OSL curve (Fig. 1). The plagioclase porphyry sample was therefore not used in the later stages of this research. Each CW-OSL curve was normalized to their initial signals. Both of the CW-OSL decay curves for quartz and albite showed a similar decreasing tendency with each decay rate. In the case of CW-OSL measurement, it could be difficult to extract the OSL emission from quartz in various kinds of grains because the OSL intensity from quartz is lower than that from albite. Therefore, it was decided that the as-received sample could not be used in CW-OSL dosimetry without performing chemical separation.

The P-OSL curves were measured using the quartz and albite samples (Figs. 2 and 3, respectively). The P-OSL was measured by a pulsed stimulation of blue-LED with an interval of 200 μs and on-time pulse of 1, 2, 4, 10 μs. In the figures, both of the P-OSL intensities are normalized to their initial intensities and are shown in a logarithmic vertical axis. From Fig. 2, the P-OSL intensity from quartz decreases to one-tenth of the initial intensity of 100 μs with all on-time pulse lengths. On the other hand, from Fig. 3, the P-OSL intensity from albite decreases to one-tenth of the initial intensity of duration shorter than 20 μs depended on on-time pulse. The P-OSL signals from quartz in a mixture sample could be separated by data extraction only. However, if the other minerals included in the sample showed bright P-OSL emissions, then quartz P-OSL dosimetry could not be applied to measure the dose. In that case, the dosimetry would need to make use of easy chemical separation.

In order to check the validity of the proposed P-OSL method, P-OSL decay curves were measured with 4 or 10 μs of LED illumination width using a mixture of equal parts of quartz and albite as shown in Fig. 4. The inset shows the normalized data on a logarithmic vertical axis. The decay curve included a quick decay component of albite and a slow decay component of quartz. Therefore, it is suggested that a P-OSL component of quartz could be extracted from a mixture of some minerals. The P-OSL emissions were relatively weak with a LED illumination width of 1 or 2 μs and therefore were excluded from this research.

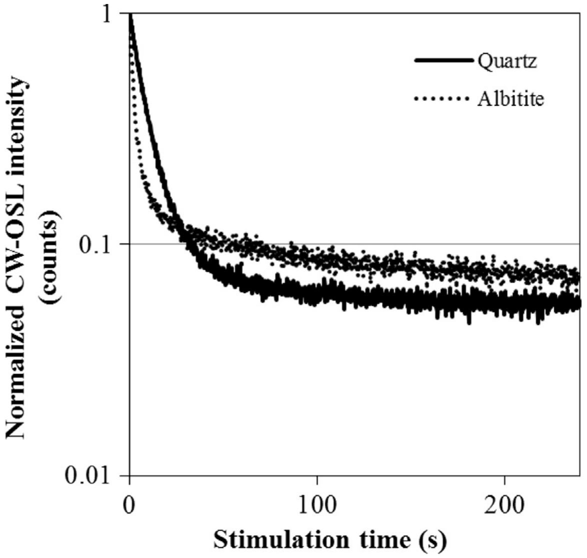

Fig. 1. CW-OSL decay curves for blue light stimulation of quartz (Q, solid line) and albite (A, dashed line).

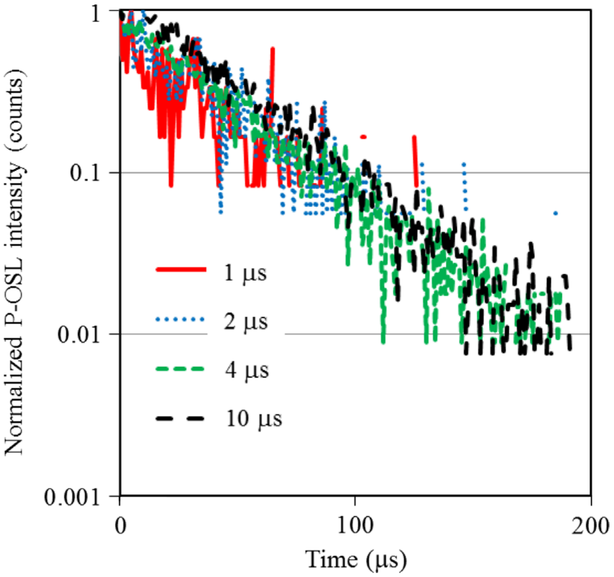

Fig. 2. P-OSL decay curves of quartz for blue light stimulation at on-time pulse of 1, 2, 4 and 10 μs.