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OSL properties of anthropological bone and tooth

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Abstract

The aim of present work was to investigate whether anthropological bone and teeth can be used in dosimetric and dating studies. The radiation dose responses of anthropological human bone and pig teeth were obtained and studied using infrared stimulated luminescence (IRSL). The radiation dose responses of these materials were found to be compatible with commonly used feldspar and quartz compounds. The IRSL signal was shown to be linear with a radiation dose until ~200 Gy and stable at ambient temperature, which may allow the use of such materials for dating.

keywords: Anthropological bone; Teeth; IRSL; Dosimetry; Dating

1. Introduction

Stimulated luminescence dating methodologies, both TL and OSL, are based on the assumption that many natural samples are able to accumulate, in trap states with a long mean life, electrons that have acquired sufficient energy from α, β and γ radiations emitted from natural radionuclides belonging to the ^{238}U, ^{232}Th and ^{40}K decay chains and from cosmic radiation. Thus, the number of electrons trapped is, within certain limits, proportional to the total absorbed dose (the energy absorbed per mass unit measured in Gray, $1\,\mathrm{Gy} = 1\,\mathrm{J/kg}$) and, consequently, the crystals are able to store information related to that quantity. Thermal stimulation (at temperatures well above room temperature) or exposure to sunlight (for appropriate times and intensities) induces the rapid emptying of the trap states with the emission, during the accompanying radiative transitions, of photons in a number proportional to the electrons released from the traps, and therefore to the total energy which determined the entrapment.

Because of the natural radioelements present, the crystals begin to accumulate a dose of radiation, known as the palaeodose. This is accumulated with an annual rate characteristic for the sample itself as well as for the environment in which the sample is buried and, if these conditions remain unvaried over time, the annual dose can be considered constant. Under these conditions, therefore, the palaeodose is proportional to burial time, in accordance with the age equation

$$t = \frac{P}{D}, \tag{1}$$

where t is the age in years, P the paleodose absorbed by crystals in Gray (Gy) and D the mean annual dose (Gy per year). The paleodose is obtained by luminescence measurements, which are strictly related to the propriety of the sample, and the age relation can be written as

$$t = \frac{L/l}{D}, \tag{2}$$

where L is the measured luminescence and l the luminescence sensitivity (the luminescence emitted per adsorbed unit dose) (Carobene et al., 2006). The response is characterized by a relation between the intensity of luminescence and the absorbed dose that can be obtained experimentally over a large range of doses up to the saturation region where the luminescence intensity is independent of the absorbed dose. D is the annual dose due to the natural radioisotope content

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of the sample and its surrounding environment expressed in Gy per year:

$$D = D_\alpha + D_\beta + D_\gamma + D_{\mathrm{cos\,mic}}. \tag{3}$$

D_α, D_β, D_γ are the alpha, beta and gamma components of the annual dose rate due to the natural radio-nuclides of the sample and the surrounding material. The annual dose can be measured using dosimeters or calculated from the U, Th and K contents of samples using alpha, beta counting or gamma ray spectrometry (Aitken, 1985; Turhan and Gündüz, 2007). The physical principles can be found elsewhere (Aitken, 1985,1998; Göksu et. al., 1991).

Optically stimulated luminescence signals from natural, inorganic quartz and feldspar samples extracted from items such as bricks, tiles, pottery, or porcelain are routinely used in the dating of geological and archaeological materials. Application of OSL for dating was first demonstrated by Huntley et al. (1985). Hütt et al. (1988) were the first to show that it was possible to stimulate a luminescence signal from feldspars using optical stimulation in the near infrared. Subsequently, Poolton and Bailiff (1989), Spooner et al. (1990), and Botter-Jensen et al. (1991) constructed units for stimulation based on systems of small IR light-emitting diodes (LEDs). The application of OSL is a widely used technique in dating archaeological and geological materials, as well as in personal and environmental dosimeters (Spooner, 1994; Poolton et al., 1995; Tanir et al., 2000, 2004; Göksu, 2003; Bailey et al., 2000; Botter-Jensen and Murray, 2001; Martini et al., 2001). Much attention has been focused on the luminescence properties of organic materials such as bone, coral skeleton and shell (Driver, 1979; Carmichael et al., 1994; Ninagawa et al., 1994; Barnes et al., 2003; Barnes and Taylor, 2005). The possibility of performing OSL measurements of dental enamel was first proposed by Godfrey-Smith and Pass (1997), who observed dose-dependent IR-stimulated and green-stimulated luminescence signals in deproteinated with sodium hydroxide (NaOH) and non-deproteinated dental enamel. That study demonstrated the feasibility of using OSL from dental enamel for radiation dosimetry using infrared stimulation luminescence (IRSL) and concluded that OSL can "become the first non-invasive, simple, reliable, and portable means of retrospective radiation dosimetry in humans" if the sensitivity can be improved by 2–3 orders of magnitude. The possible effect of variations such as different sample preparation methods, gender, age, and race on the sensitivity during the performance of OSL measurements in dental enamel is pointed out in the study performed by Yukihara et al. (2007). The need for research on this subject is also emphasized in this study.

In an old bone, the organic content has largely disappeared and therefore measurements are feasible on mammoth samples (Jasinka and Niewiadomski, 1970). If luminescence decay signal is observable from anthropological bone and teeth remains, these materials will be suitable of dating for many purposes. Therefore, in this study, IRSL properties of anthropological human bone and remains of pig teeth were investigated.

Bone and tooth are composite materials formed of organic and inorganic chemicals. The organic compounds constitute mostly collagen. The inorganic or bone/tooth mineral components constitute predominantly hydroxyapatite (HA) (Horvath, 2006). HA, made up of crystals of calcium phosphate, inorganic component of bone and tooth minerals, is a solid state integrating dosimeter (Horvath, 2006). During both the environmental irradiation and in laboratory irradiation of the sample, electrons become trapped in the HA. The traps are very stable; at room temperature, emptying of the traps occurs with a half-life of many years (Breentt and Battistat, 1995).

During burial, bone and tooth minerals usually survive much longer than collagen due to hydrolysis and dissolution of older specimens. In warm and wet environments, no usable collagen remains after 10,000 years (Horvatha, 2006). Because of these characteristics of buried bone and teeth and crystalline structure of HA, it is considered that these materials can be studied as soil in IRSL.

2. Experimental procedures

2.1. Apparatus

The apparatus (Optical Dating System 9010 Reader) used was developed by Spooner et al. The basic luminescence reader incorporates an IR LED (880 ± 80 nm) module based on the design described by Spooner et al. (1990). All data were collected using an IRSL add-on unit for the 9010 automated reader, which uses TEMT 484 IR diodes run at 40 mA, giving a power of about 30 mW/cm^2 at the sample. Luminescence was detected using a Thorn EMI 9235 QA photomultiplier tube.

2.2. Sample preparation

Anthropological bone and teeth were taken from a tomb in Mersin in Turkey. The archeologists estimate that these materials have been buried in soil for at least a 100 years. Firstly, these materials were properly washed in an ultrasonic bath to clean contamination. Trabecular bones (interior of the bone) were obtained by scraping from bone. These fractions were washed in 10% HCl and 35% H_2O_2 to remove carbonates and organic components, respectively. All of the fractions were then dried in an oven at 50 °C. After that, all samples were crushed and sieved to obtain the size fraction of about $<38\,\mu$m. Subsequently, the grains were suspended in acetone and deposited on aluminum discs of 10 mm diameter and 0.5 mm thickness. Aluminum discs were put in the bottom of small glass tubes; the suspension was put in this tube and, with the evaporation of acetone, a thin layer of sample was produced.