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Internal dose rate to K-feldspar grains from radioactive elements other than potassium

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Abstract

The concentrations of radioactive elements in K-feldspar grains were studied using electron micro-probe for potassium (K) content and inductively coupled plasma mass spectrometer (ICP-MS) for uranium (U), thorium (Th) and rubidium (Rb) contents. The K content of individual grains is 13–14%. The U, Th and Rb contents are sufficiently high to make significant contributions to the internal dose rate compared to the contribution from the K content. The U and Th contents are reduced, but not eliminated completely, by hydrofluoric (HF) acid etching.

Keywords: Luminescence dating; Internal dose rate; K-feldspar grains; U, Th, Rb concentrations; ICP-MS

1. Introduction

Optical dating has been successfully applied to a variety of materials and many research fields (Wintle, 1993, 1997; Aitken, 1998). The optically stimulated luminescence (OSL) from mineral grains, such as quartz and K-feldspar, are used as a dosimeter to estimate the radiation dose derived from environmental radiation since the last sediment deposition or heating event. This radiation dose (or equivalent dose, D_e) can be calculated by comparing the natural OSL with the OSL produced by a known laboratory dose. After measuring the dose rate (D), which is composed of the internal dose rate contributed from the decay of radioactive elements within the mineral grain itself and the external dose rate from the surrounding environment, the age of the sediment can be calculated from the equation

$$\text{Age} = \frac{D_e}{D}.$$

In most routine luminescence dating studies using K-feldspar, the dose contribution from the K content is considered to contribute to the internal dose rate (Aitken, 1998). The dose contribution from U, Th and Rb is usually considered to be negligible because of the low concentrations of U and Th in K-feldspar grains and because of the low effective dose rate from Rb. However, in the isochron dating approach using K-feldspar and quartz luminescence signals, only the internal dose rate is relevant to the age calculation (Vogel et al., 1999; Zhao and Li, 2002). Hence, the dose contribution from internal U, Th and Rb may play an important role, and should be studied in detail.

The beta particle emitted during the decay of ^{87}Rb has very low energy ($E_{max} = 0.282$ Mev) and a short ionizing range. A correlation of Rb with K content is usually used to estimate the content of Rb (Warren, 1978; Mejdahl, 1987).

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According to several researchers (Huntley and Lamothe, 2001; Huntley and Clague, 1996; Huntley, 2002; Huntley and Hancock, 2001; Readhead, 2002), it is necessary to include an estimation of the internal dose rate due to Rb, in the estimation of the annual dose of K-feldspar.

Mejdahl (1987) measured the U contents of hundreds of quartz and K-feldspar multi-grain samples by means of the delayed neutron counting technique and found that most of the samples had U contents below 0.5 ppm. He also measured the Th contents of 30 samples by means of neutron activation analysis (NAA) and found that most of the samples had Th contents below 1 ppm. Other studies suggest that the U and Th concentrations in their K-feldspar are 0.2 ppm and 0.4 ppm, respectively (Huntley and Clague, 1996; Huntley and Lian, 1999).

The U and Th contents in quartz are often considered to be so low that the dose contribution from them is negligible. The concentrations of U and Th in granitic quartz have been estimated at about 50 and 100 ppb, respectively (Rink and Odom, 1991). Han (1999) measured the U and Th concentrations in several quartz samples from granite by means of NAA and qualitatively estimated the average concentrations of U and Th to be about 51 and 129 ppb, respectively.

In this study, ICP-MS was used to measure the concentrations of U, Th and Rb inside individual quartz and K-feldspar grains. For K-feldspar grains, a variety of samples were used. To allow direct comparison between minerals, concentrations inside individual quartz and K-feldspar grains from one sample, DaLi, were measured by means of laser-ablation ICP-MS analysis. The concentrations of U, Th and Rb internal to K-feldspar for 5 multi-grain samples were also measured by means of solution ICP-MS analysis. The internal dose rate contributions based on the U, Th and Rb concentrations are presented, and implications for luminescence dating discussed.

2. Sample preparation and measurement standards

2.1. Sample preparation

K-feldspar grains were selected individually from 2 sediment samples, DaLi and D4, and 3 granite samples, Bole1, Hong4 and XG. All samples come from China. Sample DaLi is a sand and gravel sediment from an archaeological site (DaLi, Shaanxi province) and sample D4 is a dune sand sample from the north of China. Sample Bole1 is a potash granite sample from Bole county, Alataw of Xinjiang province; Hong4 is a potash granite sample from Hongshan, western Junggar of Xinjiang province; and XG is an alkaline granite sample from Miaoergou, western Junggar of Xinjiang province (Yuan et al., 2002).

2.1.1. Selection of mineral grains

Except for studying the effect of HF acid etching, all mineral grains of quartz and feldspar were selected individually, in order to simplify the discussion of the data. The manual selection was undertaken using a needle under a microscope (Leica, Zoom 2000). The sand-sized quartz and feldspar grains in the range 200–500 μm diameter were visually identified. In this grain size range, the grains are large enough to distinguish easily from each other, and at the same time are small enough to avoid major inclusions of other minerals.

2.1.2. Preparing for laser-ablation ICP-MS analysis

K-feldspar and quartz grains (∼400 μm diameter) from DaLi were selected individually under the microscope for laser-ablation ICP-MS analysis.

The individual mineral grains were fixed in a solid resin cylinder for measurements. K-feldspar grains were stuck in an array to a soft plastic lid with double-sided tape. Resin and hardener were mixed in a proportion of 15:2. The well-mixed resin and hardener were held in the container for 30 min to release any air bubbles. The resin was then poured slowly into the lid to cover all of the K-feldspar grains. After a further delay of 30 min to again allow any air bubbles to escape, the lid was put into a 50 °C oven for 24–48 h to cure the resin. After removing the soft plastic lid, the solid cylinder surface containing the K-feldspar grains was polished using polishing powder and cream until no nick was observed under a microscope. Sixteen K-feldspar grains were mounted in each of two such solid resin cylinders.

In the late stage of the study, another nine K-feldspar grains selected from sample DaLi were stuck to a piece of glass with double-sided tape, without fixing in resin and surface polishing, for laser-ablation ICP-MS analysis. Seven quartz grains selected individually from sample DaLi were mounted in the same manner, for comparison with the K-feldspar.

All the grains had been etched using HF acid (10% for K-feldspar; 40% for quartz) for 40 min to eliminate any surface contamination prior to analysis.

2.1.3. Preparing for solution ICP-MS analysis

K-feldspar grains were selected individually from 5 samples for solution ICP-MS analysis. The mass of grains intended for each solution was measured precisely.

The 3 bulk granite samples were first crushed and then sieved to obtain a grain size of about 400 μm in diameter. K-feldspar grains were selected individually under a microscope. After HF acid (10%) etching for 40 min, samples Bole1 (48.8 mg), XG (51.3 mg) and Hong4 (51.2 mg) were prepared. After polytungstate heavy liquid (2.58 g/cm^3) separation, the K-feldspar grains from D4 and DaLi were also individually selected under the microscope. The grain size of the K-feldspar in sample D4 was so small (∼200 μm) that visual selection was difficult. After the HF acid etching, only 8.8 mg of K-feldspar was obtained from sample D4, in contrast to the 48.7 mg of K-feldspar grains (∼400 μm) obtained from DaLi.

The effect of the HF acid etching was investigated by measuring three groups of K-feldspar grains (∼400 μm) from the