Earth and Planetary Science Letters 495 (2018) 56–68

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Thermoluminescence of feldspar as a multi-thermochronometer to constrain the temporal variation of rock exhumation in the recent past

R.H. Biswas [a,*], F. Herman [a], G.E. King [b], J. Braun [c,d]

[a] Institute of Earth Surface Dynamics, University of Lausanne, Switzerland
[b] Institute of Geological Sciences, University of Bern, Switzerland
[c] Helmholtz Centre Potsdam, German Research Center for Geosciences (GFZ), Potsdam, Germany
[d] Institute of Earth and Environmental Sciences, University of Potsdam, Potsdam, Germany

ARTICLE INFO

Article history:
Received 30 August 2017
Received in revised form 15 April 2018
Accepted 17 April 2018
Available online xxxx
Editor: A. Yin

Keywords:
TL of feldspar
TL-thermochronology
multi-thermochronometer
rock exhumation
Namche Barwa

ABSTRACT

Natural thermoluminescence (TL) in rocks reflects a dynamic equilibrium between radiation-induced TL growth and decay via thermal and athermal pathways. When rocks exhume through Earth's crust and cool from high to low temperature, this equilibrium level increases as the temperature dependent thermal decay decreases. This phenomenon can be exploited to extract thermal histories of rocks. The main advantage of TL is that a single TL glow curve has a wide range of thermal stabilities (lifetime <ka to Ba), and hence can provide multiple constraints on thermal histories. Here we constrain the distribution of kinetic parameters of TL in feldspar using a glow curve deconvolution method and fitting infinitesimal sub-peaks using a general order kinetic model. Each peak corresponds to a different but closely located energy level E. Forward modeling is applied for different time-temperature histories to estimate the sensitivity and limitation of each signal for different cooling rates. The results show that it is possible to constrain thermal histories between ~30 °C and ~80 °C. The results also illustrate that shallower traps, i.e. with lower activation energies, can be exploited to constrain lower cooling histories >100 °C/Ma, whereas deeper traps, i.e. with higher activation energies, provide constraints on thermal histories for higher cooling rates (>300 °C/Ma). Finally, we show how the path of rock exhumation (i.e., depth vs. time) can be constrained using an inverse approach. The newly developed methodology is applied to rapidly cooled samples from the Namche Barwa massif, eastern Himalaya to suggest a trend in exhumation rate with time that follows an inverse correlation with global temperature and glaciers equilibrium altitude line (ELA).

1. Introduction

Recent interest in Earth surface processes and the interactions between climate, tectonics and erosion has drawn attention to a wide range of methods that can be used to constrain the rate and timing of landscape evolution. One of these methods is thermochronometry, which in its simplest form consists of dating the time since a mineral passes through a closure temperature window (T_c; Dodson, 1973). There exist a range of thermochronometers with various closure temperatures (Reiners et al., 2005). Recently, there has been growing interest in constraining recent thermal histories (<1 Ma), in particular to understand Quaternary erosion processes and their potential link to climate. In this context, trapped charges dating methods such as electron spin resonance (ESR; Grün et al., 1999), thermoluminescence (TL; Johnson, 1966), optically stimulated luminescence (OSL) of quartz (Herman et al., 2010) and infrared stimulated luminescence (IRSL) of feldspar (Guralnik et al., 2015a) have been used as low temperature thermochronometers. A full review on trapped charge thermochronometry has been provided by King et al. (2016a) and Herman and King (2018). Here we revive the use of TL as a thermochronometer.

Trapped charge methods rely on the fact that rock minerals (e.g., quartz, feldspar) are exposed to radiation emitted by ambient radioactive isotopes (U, Th, K). The ionizing radiation ionizes the atoms freeing electrons and creating holes. The free electrons may be trapped at centers present in the natural crystal due to structural defects and chemical impurities. The concentration of trapped electrons at a trapping center depends on the amount of radiation and the electron's residence time (thermal and athermal) in that center. When the minerals are stimulated by heat or light in the laboratory, the trapped electrons are ejected and recombine with luminescence centers to give rise to the luminescence phenomena. Based on external stimulation, heat or light, luminescence

* Corresponding author.
E-mail address: biswasrabiul@gmail.com (R.H. Biswas).

https://doi.org/10.1016/j.epsl.2018.04.030
0012-821X/

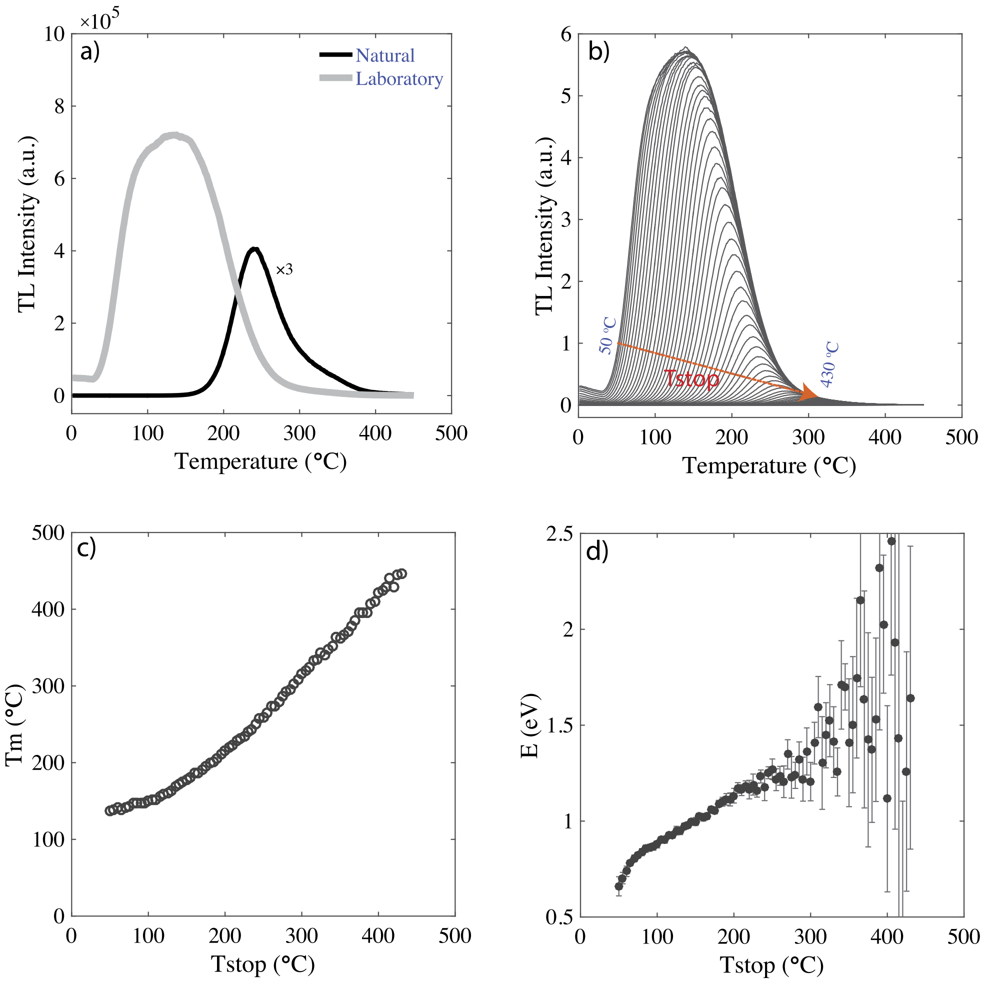

Fig. 1. a) Representative TL glow curves of a natural signal and of the same aliquot following laboratory dosing (15 Gy), b) fractional glow curves, recorded after heating the dosed (75 Gy) sample up to T_{stop}, which ranged from 50 to 430 °C at 5 °C increments. Each fractional glow curve was normalized with a fixed dose after glow. With increasing T_{stop}, the peak maxima (T_m) shifts to higher temperatures, c) plot of T_m vs T_{stop}, d) plot of activation energy obtained using the Initial rise method of fractional glow curves.

is termed as thermoluminescence or optically stimulated luminescence (details of the TL/OSL phenomenon can be found in Chen and McKeever, 1997).

Minerals in rocks are exposed to radiation for long time periods (>Ma) and the trapped electron concentration is always at an equilibrium level dictated by radiation-induced growth and decay via thermal and athermal pathways. When rocks exhume through a geothermal gradient, from high to low temperature, the equilibrium level increases as the temperature dependent thermal decay decreases. The time (or temperature) dependent change of the natural luminescence level can be exploited as a luminescence (TL/OSL) thermochronometer (King et al., 2016a).

Compared to optically stimulated luminescence (OSL/IRSL), TL glow (from room temperature to 450 °C) arises from multiple traps with lifetimes at room temperature ranging from <ka to Ba (Aitken, 1985). Each trap may be associated with a closure temperature and hence TL can be used as a multi-thermochronometer (Li and Li, 2012). The feasibility of TL as a thermochronometer was first demonstrated by Johnson (1966). TL thermochronometry was then applied to lunar boulders to predict surface temperatures (Durrani et al., 1977). Recently, a few preliminary studies have discussed the feasibility of TL-thermochronometry by testing several protocols on quartz (Tang and Li, 2015) and feldspar (Brown and Rhodes, 2017a; Brown et al., 2017b). In this study, we systematically explore the TL of feldspar minerals to estimate rock exhumation in the recent past (<500 ka). First, we show how the kinetic parameters necessary for TL-thermochronometry can be constrained. Then we report a series of forward and inverse modeling experiments to test the sensitivity and limitation of each signal, and predict the exhumation path of the rock (depth vs. time) through the geothermal field. Finally, we apply this new method to samples from the Namche Barwa massif, eastern Himalaya.

2. TL of feldspar

When dosed (natural or laboratory) samples are heated linearly (here 1 °C/s) from room to high temperature (450 °C), trapped electrons escape progressively from shallower to deeper traps. This results in TL glow curves. The TL glow curves of feldspar exhibit a broad distribution with temperature, with maximum emissions arising between 250–300 °C for natural samples and at 150–200 °C for laboratory regenerated glow curves (Fig. 1a). The TL of feldspar thus reflects either a continuous distribution of trap energies or the sum of a large number of peaks. Strickertsson (1985) examined the TL of microcline and identified six overlapping peaks from room temperature to 500 °C, while Grün and Packman (1994) studied Na- and K-feldspar and suggested that the samples followed non-first order kinetics and that TL glow curves reflect a continuous distribution of trap energies.

To understand the trap distribution of the present samples, the $T_m - T_{stop}$ method was applied (McKeever, 1980). This method con-