2012

A reply to the comments by Thomsen et al. on "Luminescence dating of K-feldspar from sediments: a protocol without anomalous fading correction"

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Abstract

We are pleased that Thomsen et al. (2012) has tested our newly proposed multi-elevated-temperature post-IR IRSL (MET-pIRIR) procedure (Li and Li, 2011) using their own samples, which provides an independent test on the validity of this procedure. In their study, Thomsen et al. (2012) found that the METpIRIR procedure gave consistent results with the two-step post-IR IRSL (TS-pIRIR) procedure originally proposed by [Thomsen et al., 2008] and [Buylaert et al., 2009] and Thiel et al. (2010), indicating the validity of both methods for their samples investigated. Based on this observation, they argued that the MET-pIRIR procedure has no advantage over the TS-pIRIR procedure, in which a 290 °C post-IR IRSL was applied after a 50 °C IRSL measurement.

Keywords

sediments, feldspar, k, dating, luminescence, al, et, thomsen, comments, reply, correction, anomalous, fading, without, protocol, CAS

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

Publication Details

Li, B. & Li, S. (2012). A reply to the comments by Thomsen et al. on "Luminescence dating of K-feldspar from sediments: a protocol without anomalous fading correction. Quaternary Geochronology, 8 49-51.

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We are pleased that Thomsen et al. (2011) has tested our newly proposed multi-elevated-temperature post-IR IRSL (MET-pIRIR) procedure (Li et al., 2011) using their own samples, which provides an independent test on the validity of this procedure. In their study, Thomsen et al. (2011) found that the MET-pIRIR procedure gave consistent results with the two-step post-IR IRSL (TS-pIRIR) procedure originally proposed by Thomsen et al. (2008), Buyleart et al. (2009) and Thiel et al. (2011), indicating the validity of both methods for their samples investigated. Based on this observation, they argued that the MET-pIRIR procedure has no advantage over the TS-pIRIR procedure, in which a 290°C post-IR IRSL was applied after a 50°C IRSL measurement.

However, it is to be noted that the samples investigated in their study are limited to those samples with relatively small natural dose (<250 Gy). Since the effect of anomalous fading is strongly dependent on the natural dose received (Li and Li, 2008), a small anomalous fading rate might not be so effective in age estimation for samples with small natural dose. It can cause significant age underestimation for old samples with large natural doses. Hence, it is not surprising that the MET-pIRIR procedure and TS-pIRIR procedure give similar results for these samples, because of the small anomalous fading rate found in the pIRIR signals in their natural dose range (<250 Gy).

In order to checking whether a procedure is able to reduce the effect of anomalous fading rate to a negligible level, this method should be tested using older samples with larger natural doses. In our original paper (Li and Li, 2011), only one sample, FJGW1, was used for comparing the MET-pIRIR method and the TS-pIRIR method, which is not conclusive. Here we have further studied 6 loess samples, covering a wider range of sedimentary ages and natural doses, from the Luochuan section in the Chinese Loess Plateau. These samples are selected for testing the validity of dating procedures because the chronology of loess from the Luochuan section has been well established (Ding et al., 2002) and independent age controls can be obtained based on their stratigraphic positions. A summary of the samples, sampling depth, expected ages and doses, dose rate is shown in Table 1.

In this study, three measurement procedures were conducted. The first is the MET-pIRIR procedure (Li and Li, 2011), in which the infrared stimulated luminescence (IRSL) signal were measured by progressively increasing the stimulation temperature from 50 to 300 °C in step of 50°C and used a preheat of 320 °C for 60 s. It is noted that the highest stimulation temperature used in this study was different from the 250°C in the original paper of Li and Li (2011). This is because we found that it is necessary to use a higher stimulation temperature in the MET-pIRIR procedure in order to obtain an age plateau for old loess samples. This point was discussed in detail in Li and Li (submitted). Here only the MET-pIRIR signals at 250 °C were used for comparison, which is comparable to the results obtained using the original procedures proposed by Li and Li (2011). The second procedure is exactly following that proposed by Thiel et al (2011), in which a post-IR measurement at 290 °C was conducted after the 50 °C IRSL measurement, named pIRIR (50, 290). The third procedure is similar to the second one, except that the prior IRSL measurement was conducted at 200 °C instead of 50 °C. The pIRIR measurement was conducted at 290 °C, called pIRIR (200, 290). The three procedures are compared in Table 2.

The equivalent doses and expected doses, obtained from expected ages and dose rates, are compared in Fig. 1. For the youngest sample investigated, LC-096, the expected dose (273 Gy) are consistent with the measured equivalent doses obtained by all 3 procedures within ±1σ errors. For sample LC-120, of which the expected dose is 425 Gy, the results of MET-pIRIR (250) and pIRIR(200, 290) are consistent with the expected dose within ±1σ errors. The result of the pIRIR(50, 290) is slightly lower than the expected dose but still consistent with each other within ±2σ errors. For these two younger samples, our results is consistent with the founding of Thomsen et al (2011), in which no distinctive difference was observed between the MET-pIRIR (250) and pIRIR(50, 290) results. For older samples, the MET-pIRIR (250) gave consistent results with the expected doses up to ~900 Gy. However, the results obtained using the pIRIR(50, 290) signal starts to get underestimated for samples with expected dose larger than ~500 Gy. The larger doses are, the larger extents of underestimation are observed for the samples. It interesting to note that, by increasing the stimulation temperature in the prior IRSL measurement from 50 to 200 °C, the underestimation in age disappeared for the TS-pIRIR procedure. The results from pIRIR(200, 290) are consistent with the expected doses for all samples except one, sample LC-205.

The results shown in Fig. 1 can be explained using recent model proposed for feldspar IRSL. It has been suggested that a higher IRSL stimulation temperature may access to more stable (non-fading) trapped charges (Poolton et al., 2002; Li, 2010; Jain and Ankjærgaard, 2011). In a study of the relationship between IRSL decay curve shape and anomalous fading, Li (2010) showed that post-IR IRSL at elevated temperatures can access those easy-to-fade electron-hole pairs, which are not accessible by low temperature IRSL. It is indicated that a higher stimulation temperature used in the first IR stimulation will remove more easy-to-fade signals than stimulation at low temperature does. A similar conclusion was also reached by Jain and Ankjærgaard (2011), who suggested that IR stimulation at elevated temperature will swipe a larger volume of electron-hole pairs, which causes a preferential removal of spatially close electron-hole pairs corresponding to the easy-to-fade signals. Therefore, it is expected that a progressive increase of stimulation temperature used in MET-pIRIR protocol will progressively remove the easy-to-fade electron-hole pairs, in a better way than a single IR stimulation at low temperature. The results that the pIRIR(50, 290) signals get underestimation at higher doses (Fig. 1) confirmed that a short IR bleaching in laboratory (up to several hundred seconds) at 50 °C cannot completely remove all of the charges in easy-to-fade traps. Further evidence was shown by the observation that the underestimation in $pIRIR_{290}$ disappeared by increasing the prior IRSL stimulation temperature from 50 to 200 °C (Fig. 1), indicating that a high-temperature IRSL can remove more easy-to-fade signals than the low-temperature IRSL. However, the MET-pIRIR protocol still have the advantage over the TS-pIRIR procedure in checking whether a non-fading component has been achieved from the 'age plateau' in the age-temperature plot (Li and Li, 2011).

In summary, based on our new results shown in Fig. 1, it is concluded that:

1) The pIRIR(50, 290) can give reliable results for those samples with relatively small natural doses, e.g. <400 Gy. This is consistent with the findings by Thomsen et al (2011). But underestimation might be resulted for older samples with larger natural doses (>400 Gy). This is consistent with the dose-dependent change of the anomalous fading rate in the pIRIR(50, 290) signals (Li and Li, 2008).
2) The two-step pIRIR procedure has potential to achieve a real non-fading signal by increasing the stimulation temperature of the prior IRSL measurement. A temperature as high as 200 °C is necessary.

3) The MET-pIRIR (250) signal has negligible anomalous fading rate for our samples, and they can give reliable results up to ~900 Gy. It has advantages in checking for the reliability of the dating results.

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Figure caption:

Fig. 1: Comparison of the expected doses (see Table 1 for details) and the equivalent doses obtained using different protocols in Table 2. The MET-pIRIR (250) data shows the results obtained from the 250 °C MET-pIRIR signals. See Li and Li (submitted) for the results obtained from the other MET-pIRIR temperatures. The straight line is the 1:1 line.

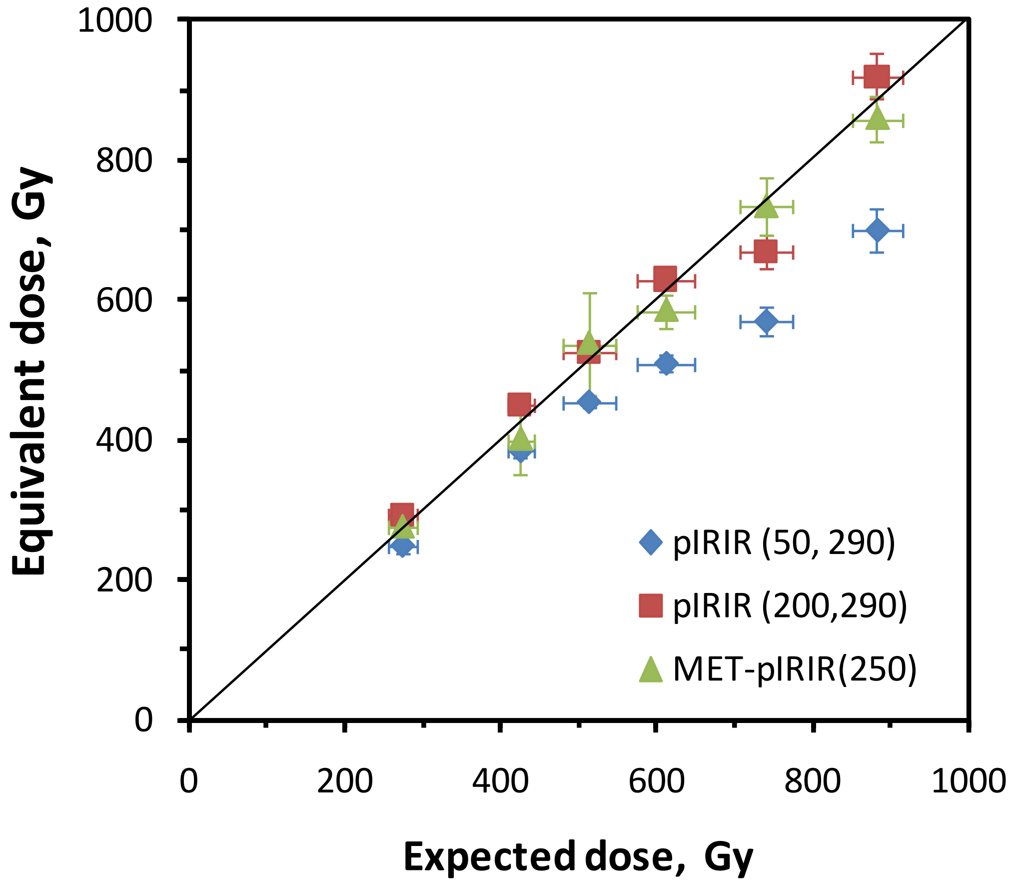
1000
800
600
400
200
0
0
200
400
600
800
1000
Equivalent dose, Gy
Expected dose, Gy
pIRIR (50, 290)
pIRIR (200,290)
MET-pIRIR(250)

Figure 1

Table 1: Summary of the samples, depth, expected ages and doses, dose rate and equivalent doses.

Sample	Depth (m)	Expected age (ka) [a]	Dose rate (Gy/ka)	Expected dose (Gy) [b]	Equivalent dose (Gy)		
					MET-pIRIR (250)	pIRIR(50, 290)	pIRIR(200, 290)
LC-096	9.6	75±5	3.6±0.1	273±18	275±13	250±11	293±11
LC-120	12.0	124±5	3.5±0.1	425±17	401±49	385±11	450±8
LC-150	15.0	152±10	3.4±0.1	512±34	537±75	455±9	525±5
LC-170	17.0	170±10	3.6±0.1	612±36	585±24	510±13	630±15
LC-205	20.5	214±10	3.5±0.1	740±35	733±41	570±20	670±23
LC-230	23.0	263±10	3.4±0.1	883±34	859±34	700±31	920±33

Note: [a] The expected ages are the stratigraphic ages estimated from linear interpolation of their stratigraphic positions into the corresponding loess/paleosol boundary ages in which the samples were embedded (Ding et al. 2002). See Li and Li (submitted) for a detailed description of the samples and their stratigraphic ages.

[b] The expected doses were calculated using the expected ages multiplied by the dose rate for each sample.

Table 2: The procedures of MET-pIRIR, pIRIR(50, 290) and pIRIR(200, 290) measurement protocols.

MET-pIRIR protocol		
Step	Treatment	Observed
1	Give regenerative dose, D_i [a]	
2	Preheat at 320°C for 60 s	
3	IRSL measurement at 50°C for 100 s	$L_{x(50)}$
4	IRSL measurement at 100°C for 100 s	$L_{x(100)}$
5	IRSL measurement at 150°C for 100 s	$L_{x(150)}$
6	IRSL measurement at 200°C for 100 s	$L_{x(200)}$
7	IRSL measurement at 250°C for 100 s	$L_{x(250)}$
8	IRSL measurement at 300°C for 100 s	$L_{x(300)}$
9	Give test dose, D_t	
10	Preheat at 320°C for 60 s	
11	IRSL measurement at 50°C for 100 s	$T_{x(50)}$
12	IRSL measurement at 100°C for 100 s	$T_{x(100)}$
13	IRSL measurement at 150°C for 100 s	$T_{x(150)}$
14	IRSL measurement at 200°C for 100 s	$T_{x(200)}$
15	IRSL measurement at 250°C for 100 s	$T_{x(250)}$
16	IRSL measurement at 300°C for 100 s	$T_{x(300)}$
17	IR bleaching at 325°C for 100 s	
18	Return to step 1	

pIRIR(50,290) protocol		
Step	Treatment	Observed
1	Give regenerative dose, D_i [a]	
2	Preheat at 320°C for 60 s	
3	IRSL measurement at 50°C for 200 s	$L_{x(50)}$
4	IRSL measurement at 290°C for 200 s	$L_{x(290)}$
5	Give test dose, D_t	
6	Preheat at 320°C for 60 s	
7	IRSL measurement at 50°C for 200 s	$T_{x(50)}$
8	IRSL measurement at 290°C for 200 s	$T_{x(290)}$
9	IR bleaching at 325°C for 40 s	
10	Return to step 1	

pIRIR(200,290) protocol		
Step	Treatment	Observed
1	Give regenerative dose, D_i [a]	
2	Preheat at 320°C for 60 s	
3	IRSL measurement at 200°C for 200 s	$L_{x(50)}$
4	IRSL measurement at 290°C for 200 s	$L_{x(290)}$
5	Give test dose, D_t	
6	Preheat at 320°C for 60 s	
7	IRSL measurement at 200°C for 200 s	$T_{x(50)}$
8	IRSL measurement at 290°C for 200 s	$T_{x(290)}$
9	IR bleaching at 325°C for 40 s	
10	Return to step 1	

[a] For the ‘natural’ sample, i= 0 and $D_0 = 0$. The whole sequence is repeated for several regenerative doses including a zero dose and a repeat dose.