*Supplementary Data 1*

Optically Stimulated Luminescence Dating

The OSL technique relies on the fact that, the luminescence clock of sediment resets to zero by day light exposure during erosion and transportation of minerals constituting the sediments (Aitken, 1998). This implies that at the time of burial, the luminescence in the mineral is typically zero or a near zero residual value. On deposition, day light exposure ceases and a re-induction of luminescence via irradiation from local radioactivity begins and this continues unabated until sample excavation. For fluvial deposits from the Himalaya, two complication can arise. First, sediments deposited in high energy fluvial environments may experience heterogeneous and/or incomplete zeroing. If not corrected for, it may lead to overestimated ages. Second, quartz in the Himalayan region has low OSL sensitivity and hence minor contamination from feldspars can affect the results (Ray and Srivastava, 2010). Both factors are however manageable by careful sample preparation and measurement strategy. In the present study, the bleaching analysis indicated sediments to be well bleached (discussed later) and therefore the weighted mean of the palaeodoses was considered in final age calculations.

*Laboratory Protocol:* Standard chemical pretreatment was given to all samples to separate clean quartz at the Luminescence dating lab at the Wadia Institute of Himalayan Geology (Srivastava et al., 2006; 2008). 90-150 µm fraction was etched using 40% HF for 80 min, followed by 40 min treatment with 12 N HCl to remove 10-15 µm alpha affected the outer skin of the grain and dissolved feldspars. Feldspar contamination was tested using Infrared Stimulated Luminescence (IRSL) (Supplementary Fig. 1sa).

The luminescence of quartz grains was measured on a Riso TL/ OSL-20 system with a 40 sec, blue LEDs stimulation (470 nm) with sample temperature of 125 °C. Light detection was using an EMI 9235QA PMT coupled to Schott BG-39 and Hoya U-340 optical filters. A 5-points single aliquot regeneration (SAR) protocol with an IR prewash with preheat of 220 °C/10 s and cut heat of 160 °C was used for palaeodose estimation (Murray and Wintle, 2000; Jain and Singhvi, 2001). The palaeodose of 30-35 discs was calculated using photon counts of initial 5 channels (1 channel = 0.16 s) of the shine-down curve. Typical acceptance criterion was a preheat plateau of 220° C, low recuperation <5%, dose recovery test and recycling ratios within 10%; (see Supplementary data-1A, Figure 2s). For dose rate calculations, U, Th and K concentrations were measured using XRF and ICP-MS.

Infrared Stimulated Luminescence (IRSL) is performed on all samples to check the feldspar contamination (Fig 1sa). Those samples showed more than 200 IRSL counts under IRSL stimulation, were re-etched with 40 % HF for 10 min and retested for their IRSL stimulation (Fig. 1sb).

*(A) Dose recovery, Preheat Plateau and dose distribution*

The influence of preheat on the palaeodose measurement can be tested using Dose recovery and Preheat plateau tests. The dose recovery test incorporates bleaching without heating followed by administering a known dose and its recovery using Single Aliquot Regeneration (SAR) protocol at different preheat temperatures (200° C to 260° C), for preheat plateau test, the preheating was done at incremental temperatures between 180° C to 270° C (Murray and Wintle, 2003; Buylaert et al., 2008). In this test, the sample were bleached with blue light at room temperature for 40 seconds followed by β - irradiation (laboratory dose) equivalent to palaeodose (De) and recovered using SAR protocol. 14 samples out of 33, were subjected to check the suitability of preheat temperature through these tests. The recuperation ratio becomes important for these tests when two temperatures having approximately same palaeodose. The preheat plateau as shown in the figure 2s (a) is almost flat between 200° C to 240° C and the dose recovery is more precise at 220° C. Hence these tests shows that 220° C is well suited for palaeodose measurements. Figure 2s (b) shows recuperation ratio of each aliquot as plotted against different preheat temperatures. The ratio is minimum between 200-240 ° C on the sample LD-1047. Figure 2s (b) also exhibits results of dose recovery test on the same sample where 133 Gy of laboratory dose was given and was recovered at all the temperature from 200° C to 260° C. The plot also indicates minimum scattering of palaeodose between 200° C and 220° C.

Probable density distribution, radial plots of paleodoses, natural luminescence decay with time, sensitivity corrected growth curve and shine down curve were also checked before palaeodose calculations (Fig. 3s). The probable density distribution of the tested samples show a bimodal distribution of paleodoses (Fig.3sa) which may suggest inhomogeneous bleaching history of the sample. Similarly radial plot shows large number of aliquots lied within 2 σ error limit (Fig. 3sb). Figure 3sc shows a typical quartz shine down curve as luminescence signal dropped down to less than 10% in 10s. Figure 3sd shows a typical SAR growth curve. Figures 4a to 4d show radial plots of all the samples.

*(B) Bleaching history*

We performed bleaching test on all samples as per the methods suggested by Clarke (1996) and Colls et al. (2001). In this method the ratio of standard deviation to the mean palaeodose, called as coefficient of variation (Sn), provides measure of bleaching. The values of Sn, < 0.05 refers to well-bleached; 0.05-0.1, refers to moderately well bleached; 0.1 - 0.15, moderately partially bleached; > 0.15, partially bleached (Clarke, 1996). Likewise, in well bleached sample, natural intensity of each aliquot may vary significantly but this should be independent of scattering in the palaeodose. Thus, the correlation coefficient (R2) of palaeodose and their natural intensities of each aliquot should be able to tell about bleaching history (Colls et al., 2001). The correlation coefficient (R2), < 0.6 refers to well bleached and > 0.6 partially bleached and the results indicated that all the 33 samples are well bleached (table 1s). The coefficient of variation (Sn) and correlation coefficient (R2) both show 21 samples are moderately to well bleached, shown in Table 1s. Therefore to calculate the ages we utilized the weighted mean of all the paleodoses.

Reference

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Figure 1s (a) The preheat plateau test of sample LD-1047 representing the palaeodose is a function of preheat temperature. (b) A known dose (shown as dotted line) is recovered on variable preheat temperature ranging from 180° C to 270° C. At 220° C, the recovered palaeodose is very close to given dose (known dose) with low recuperation ratio.

Figure 2s The Luminescence characteristics of the sample LD-1047. (a) The frequency histogram distribution of palaeodoses of sample LD-1047 showing narrow range of palaeodose. (b) In the radial plot of the palaeodoses, the red circles are with the 2 σ error, which contribute to the weighted mean age. (c) The probable density distribution of palaeodoses. (d) Natural shine down curve of single aliquot of 70 – 125 µm quartz. (e) The sensitivity corrected growth curve of the same aliquot.

Figure 3s. (A) Infrared Stimulated Luminescence response of all the dated samples. (B) IRSL response after Re-etching. Note that 7 out of 33 samples showed IRSL counts above 200 where double SAR protocol was used to further reduce the feldspar contamination.

Figure 4sa,b.c,d Showing Radial plots paleodoses of all the samples analyzed and discussed in the study

Table 1s Bleaching history of every sample is explained by coefficient of variation (Sn) and correlation coefficient (R2).

Table 1s

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sr no.** | **Lab No** | **Field Name** | **Sn** | **R2** | **Well Bleached (+) / Poorly Bleached (-)** |
|
| **Mahe** | | | | | |
| 1 | LD-1433 | IR-1 | 0.231 | 0.15 | (-)/(+) |
|
| 2 | LD-1047 | IND-15 | 0.15 | 0.09 | (+)/(+) |
|
| **Niornis** | | | | | |
| 3 | LD-1048 | IND-16 | 0.23 | 0.48 | (-)/(+) |
|
| **Kiari** | | | | | |
| 4 | LD-1063 | IND-17 | 0.20 | 0.03 | (-)/(+) |
|
| **Gaik** | | | | | |
| 5 | LD-1064 | IND-18 | 0.22 | 0.02 | (-)/(+) |
|
| 6 | LD-1065 | IND-19 | 0.13 | 0.02 | (+)/(+) |
|
| **Tirido** | | | | | |
| 7 | LD-1066 | IND-20 | 0.16 | 0.06 | (-)/(+) |
|
| 8 | LD-1067 | IND-21 | 0.22 | 0.28 | (-)/(+) |
|
| **Hymia** | | | | | |
| 9 | LD-1068 | IND-22 | 0.21 | 0.002 | (-)/(+) |
|
| 10 | LD-1069 | IND-23 | 0.10 | 0.18 | (+)/(+) |
|
| **Upshi** | | | | | |
| 11 | LD-1070 | IND-24 | 0.16 | 0.11 | (-)/(+) |
|
| 12 | LD-1046 | IND-14 | 0.20 | 0.02 | (-)/(+) |
|
| **Kharu** | | | | | |
| 13 | LD-1045 | IND-13 | 0.22 | 0.05 | (-)/(+) |
|
| **Stakna** | | | | | |
| 14 | LD-1015 | IND-8 | 0.14 | 0.003 | (+)/(+) |
|
| 15 | LD-1016 | IND-9 | 0.17 | 0.01 | (-)/(+) |
|
| 16 | LD-1044 | IND-12 | 0.19 | 0.28 | (-)/(+) |
|
| **Stakna 1** | | | | | |
| 17 | LD-1017 | IND-10 | 0.04 | 0.113 | (+)/(+) |
|
| 18 | LD-1043 | IND-11 | 0.16 | 0.0531 | (-)/(+) |
|
| **Stakna 2** | | | | | |
| 19 | LD-985 | IND-25 | 0.09 | 0.02 | (+)/(+) |
|
| 20 | LD-986 | IND-26 | 0.35 | 0.31 | (-)/(+) |
|
| **Spituk** | | | | | |
| 21 | LD-1003 | IND-47 | 0.16 | 0.51 | (-)/(+) |
|
| **Nimu** | | | | | |
| 22 | LD-1221 | ZIC-1 | 0.12 | 0.03 | (+)/(+) |
|
| **Saspol** | | | | | |
| 23 | LD-1000 | IND-44 | 0.22 | 0.001 | (-)/(+) |
|
| 24 | LD-990 | IND-43 | 0.11 | 0.24 | (+)/(+) |
|
| **Nurla** | | | | | |
| 25 | LD-989 | IND-42 | 0.13 | 0.44 | (+)/(+) |
|
| **Khalsi** | | | | | |
| 26 | LD-997 | IND-39 | 0.16 | 0.17 | (-)/(+) |
|
| 27 | LD-996 | IND-38 | 0.25 | 0.15 | (-)/(+) |
|
| 28 | LD-998 | IND-40 | 0.17 | 0.38 | (-)/(+) |
|
| **Dumkhar** | | | | | |
| 29 | LD-995 | IND-37 | 0.22 | 0.22 | (-)/(+) |
|
| **Skyurbuchan Gompa** | | | | | |
| 30 | LD-988 | IND-36 | 0.16 | 0.01 | (-)/(+) |
|
| **Skyurbuchan Downstream** | | | | | |
| 31 | LD-987 | IND-33 | 0.15 | 0.50 | (-)/(+) |
|
| 32 | LD-993 | IND-34 | 0.16 | 0.14 | (-)/(+) |
|
| **Biamah** | | | | | |
| 33 | LD-991 | IND-31 | 0.21 | 0.24 | (-/(+) |
|