

QUARTZ OSL DATING OF SAND DUNES IN GHAGGAR BASIN,
NORTHWESTERN INDIA

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Key words: north margins of the Thar Desert; Ghaggar River; dune sand; environmental
change; OSL dating

Running title: QUARTZ OSL DATING OF SAND DUNES IN GHAGGAR BASIN,
NORTHWESTERN INDIA

Received 28 July 2011

Accepted 23 April 2012

Abstract: Several studies have used luminescence dating to investigate sand mobilization activity in extreme western areas and the southern margin of the Thar Desert, India. However, room exists for a chronology of sand profiles for the northern margins of the Thar Desert. The Ghaggar River flood plain at Rajasthan, northwestern India, in the northern margin of the Thar Desert, is bordered by sand dunes. Elucidation of the environmental changes of the Ghaggar Basin requires knowledge of many aspects of sand dune formation.

We measured optically stimulated luminescence (OSL) using the single aliquot regenerative-dose (SAR) protocol for sand of eight paleo-dunes and two flood silts of both sides of the present Ghaggar Basin and Chautang Basin flood plains. Their OSL ages were obtained respectively, as 15–10 ka or 5 ka, and 9–8 ka. Results of this study reinforce the hypothesis that sand dune deposition had started or had already been completed by 15–10 ka. Aeolian deposition was subdued by enhanced moisture during 9–8 ka. Our interpretation is that, at least since 5 ka, the scale of the flood plain of the Ghaggar River has remained equivalent to that of the present day.

1. INTRODUCTION

Embraced by long arms of sand dunes, the Ghaggar River flood plain in the northern margins of the Thar Desert is located at Rajasthan, northwestern India (**Fig. 1**). These dune arms, which comprise linear and parabolic dunes, extend from the southern Thar Desert. The dunes are from several to several tens of meters high and ca. 500 m long on average. Aeolian activity in the sand dunes is restricted to periods when south-west monsoon winds prevail (Kar, 1993). Although aeolian activity occurs in regions with a precipitation regime of <250 mm/a in the Thar Desert, the dunes in Ghaggar Basin have been stable in areas with 200–250 mm annual rainfall (Juyal *et al.*, 2003; Singhvi and Kar, 2004).

Using thermoluminescence (TL), Chawla *et al.* (1992) investigated dunes in the western extremity of the Thar Desert, western Rajasthan, considering the residual TL level. Their data suggest a peak in sand mobilization activity at ca. 14 ka. Since then, sand mobilization decreased because of the proliferation of moisture during 13–6 ka. Singhvi *et al.* (1982) measured the ages of stabilized sand dunes in the southern margin of the Thar Desert, Rajasthan, using TL, considering the residual TL level. The ages of the greatest depth of sand dunes were indicated as 16,190 a and 20,280 a. Juyal *et al.* (2003) used blue-green light-stimulated luminescence with the multiple aliquot protocol to measure aeolian deposits in the southern margin of the Thar Desert, eastern Gujarat. Their main conclusions were that the dune deposition commenced at around 26 ka, corresponding to Oxygen Isotope Stage-3, and that it continued episodically until ca. 5

ka. During 12–8 ka, aeolian deposition was subdued because of enhanced moisture. Saini and Mujtaba (2010), used optically stimulated luminescence (OSL) dating based on the single aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2000). They found that the paleochannel identified between Fatehabad and Hosanga, in the northwestern part of Haryana, received sufficient water supplies between 5.9 ka and 4.3 ka. However, the chronology of sand profiles in the northern margins of the Thar Desert remains as an unsettled question. The present study, using OSL dating with SAR protocol, reveals the age of sand dunes and flood silts existing on both sides of the present flood plain of Ghaggar Basin, located in the north margins of the Thar Desert. Ascertaining the age of the sand dune formation is important for understanding environmental changes that have taken place in the Ghaggar Basin.

2. FIELD AND SAMPLING

Samples for OSL dating were collected from eight paleo-dunes (Sisarkhas, Maiyer, Bhodasar, Rangmahal, Bhakrawala, Lal Pura Sikhan, 43GB) and two flood silts (Farmana, 4MSR) located on both sides of the present flood plain of the Ghaggar Basin and its branch, the Chautang Basin (**Fig. 1**). Two paleo-dunes near Lal Pura Sikhan were sampled. These samples were dune sand (**Fig. 2a**). The dune samples were collected near the base of each sand dune as much as possible. Two flood silt layers were sampled from archeological sites of Farmana and near 4MSR village. Two samples were silty sand (**Fig. 2b**). The Research Institute for Humanity and Nature, Japan excavated the

Farmana site during years 2006–2008 (Shinde *et al.*, 2011). This site dates from pre/early to mature Harappan. The archeological site near 4MSR, located on the right bank of the Ghaggar River, dates from the early-to-mature Harappan era. Samples for use in OSL dating were collected from flood silt under archeological sediment. Moreover, a sample for radiocarbon (^{14}C) dating, a shell, was collected from archeological sediment of the archeological site near 4MSR for comparison with the OSL age of flood silt.

Sampling sites were covered with an opaque cloth. All samples were collected after the top surface layer, which was ca. 5 cm thick, had been removed. The upper sample is No. 1 and the lower sample is No. 2 at each site. The interval between the upper and lower sample position was about 1 m (**Fig. 3**). Additional samples were collected from the sand dune immediately surrounding the OSL sample for estimation of the dose rate (annual dose) of the sand dune.

3. OSL DATING

Sample preparation and instrumentation

Minerals in each collected sample were separated roughly into fine and coarse grains (CG) in water. Dried CG samples were sieved into a fraction of 250–50 μm using standard sieves. The sieved samples were treated with 10% H_2O_2 for 16 hr and 20% HCl for 90 min. Initially non-magnetic minerals were separated from magnetic minerals using a Franz magnetic separator. Feldspar, quartz and all non-magnetic minerals were

treated together with 20% HF for 90 min and 46% HF for 10 min to separate the quartz from the others and to etch the outer part of the grains. The etched quartz fraction was sieved into 150–75 μm . The purity of quartz extracts was verified using infrared stimulation. If feldspar had remained, HF treatment was repeated.

OSL was measured using an OSL/TL reader (NRL-99-OSTL; Neorark Corp.) (Nagatomo *et al.*, 2007; 2009) equipped with an array of 32 blue LEDs (470 nm) at Nara University of Education (NUE), Japan. The OSL from a sample was detected using a PMT tube (R1140P; Hamamatsu Photonics KK, Japan) housed in a cooling unit (-20°C) through two condensing lenses and a filter (2 mm thick Hoya U-340; Kenko Tokina Corp.). Irradiation was conducted using a Risø $^{90}\text{Sr}/^{90}\text{Y}$ beta-ray source built into the OSL reader at NUE.

Paleodose and annual dose estimation

Respective paleodoses were measured using the SAR protocol shown in **Table 1**. After each regenerative-dose OSL signal (L_i) was measured, a small test dose (3 Gy) was applied. Then its OSL signal was measured (T_i) to monitor for sensitivity changes. Each sensitivity-corrected OSL for doses was calculated by dividing L_i by the respective T_i (i.e. L_i / T_i). The SAR protocol consists of a series of regenerative and test-dose measurements to create a sensitivity-corrected growth curve onto which the sensitivity-corrected natural OSL signal ($L_{\text{natural}} / T_{\text{natural}}$) is interpolated to obtain a paleodose value. To select appropriate preheat conditions using the SAR protocol, a preheat temperature plateau and dose recovery test were conducted. Preheat

temperatures at 200–280°C at intervals of 20°C for 60 s were tested. The cut-heat was 160°C. A plateau of preheating was found at 200–240°C (**Fig. 4**). Therefore, we selected a preheat temperature 230°C for routine determination. A thermal transfer test (Wintle and Murray, 2006) was performed for each sample. Recuperation was <10% for all samples. The dose recovery test ($n=3$) was within $\pm 10\%$ of the administered dose. The result suggests that the SAR procedure can recover a laboratory dose.

Annual doses (dose rate) were measured using a gamma-ray spectrometer. The concentrations of U, Th, and K in the samples were analyzed using a Ge gamma-ray detector (EGSP 8785; Eurisys Mesures) at NUE. The annual dose was calculated using the dose-rate conversion factors of Adamiec and Aitken (1998). Contributions of the cosmic-dose rate to the annual dose were assumed according to methods proposed in previous studies by Prescott and Hutton (1994), Nagatomo *et al.* (2009), and Shitaoka *et al.* (2009).

4. RESULTS AND DISCUSSION

The OSL decay curve and growth curve for 43GB (No. 2) are shown in **Fig. 5**. The growth curve can be well fitted to the exponential form. The OSL ages are presented in **Table 2**: the ages of sand dunes bordering both sides of the Ghaggar River were 15–10 ka or 5 ka (**Fig. 3**). The OSL ages of sand dunes in this study are fairly consistent with the results reported by Singhvi *et al.* (1982), Chawla *et al.* (1992), Juyal *et al.* (2003), and Saini and Mujtaba (2010). Results show that dune-building activity in the Thar

Desert had already started at ca. 26–10 ka and that it continued until ca. 5 ka.

The OSL ages of flood silts were 9–8 ka. Plural samples of carbonized wood collected from the artifact horizon of the Farmana archeological site were subjected to ^{14}C dating (Paleo-labo AMS dating group, 2011). The calibrated ^{14}C ages using IntCal09 (Reimer *et al.*, 2009) were between 4,570 and 4,160 cal a BP (2 sigma). Conventional ^{14}C ages of shells collected from the artificial horizon of 4MSR were $4,310 \pm 40$ aBP (Beta-280477). The calibrated ^{14}C ages using IntCal09 (Reimer *et al.*, 2009) were 4,970–4,830 cal a BP (2 sigma). The OSL ages, 7.9 ± 0.3 ka of Farmana flood silt and 8.4–9.0 ka of 4MSR flood silt were stratigraphically consistent with the calibrated ^{14}C ages.

The period of enhanced moisture was 13–6 ka at the western extremity area of the Thar Desert (Chawla *et al.*, 1992) and 12–8 ka at the southern margin (Juyal *et al.*, 2003). Despite some regional variations of the Thar Desert, results clarify that moisture was present in any region of the Thar Desert during 9–8 ka. The obtained OSL ages show that sand dunes commenced piling up at 10–15 ka and that they had already existed at this location since 5 ka, and that aeolian deposition was subdued because of enhanced moisture during 9–8 ka. This can be interpreted as indicating that the scale of the Ghaggar River flood plain has remained roughly equal to that of the present day since at least 5 ka.

5. CONCLUSION

We measured OSL ages using the SAR protocol for sand of eight paleo-dunes and two flood silts in Ghaggar Basin, in the north margins of the Thar Desert. The obtained OSL ages were, respectively, 15–10 ka or 5 ka, and 9–8 ka. These OSL ages are fairly consistent with results obtained for other areas of the Thar Desert. Results show that the deposition of sand dunes had started and had already existed at 15–10 ka or 5 ka in Ghaggar Basin. A period of dormancy of sand dunes for moisture occurred during 9–8 ka.

ACKNOWLEDGMENTS

We wish to thank Drs. V. Shinde, M. Kumar, P. Shirvalkar and V. Dangi for their advice and help in fieldwork, and Drs. J. Yamamoto, K. Takemura and A. Uesugi, who provided many useful comments. This study was supported by the Environmental Change and the Indus Civilization (project 3-3) research project managed by the Research Institute for Humanity and Nature, Japan.

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Figure captions and Table titles

Figure 1. Location map of this study and relation between OSL ages of eight paleo-sand dunes and flood plain of the Ghaggar River.

Figure 2. Typical results of grain-size distributions at dated sites: a) Bhakrawala; b) 4MSR.

Figure 3. Representative sections of paleo-sand dunes (a ~ h) and flood silts (i ~ j) at sampling locations: a) Sisarkhas; b) Maiyer; c) Bhodasar; d) Rangmahal; e) Bhakrawala; f) Lal Pura Sikhan-1; g) Lal Pura Sikhan-2; h) 43GB; i) Farmana; j) 4MSR.

Figure 4. Preheat temperature plateau measurement of 43GB (No. 2). Averages of three aliquots are shown at respective temperatures. A preheating plateau is apparent at 200–240°C.

Figure 5. a) OSL decay curve of natural and 50 Gy for Maiyer (No. 1). b) Growth curve of an aliquot of Maiyer (No. 1) for regenerative doses of 0, 10, 20, 30, 40, and 50 Gy. A recycling point (open circle) is denoted as 10 Gy. The recycling ratio is 1.06.

Table 1. Protocol for SAR measurement.

Table 2. Results of OSL dating.

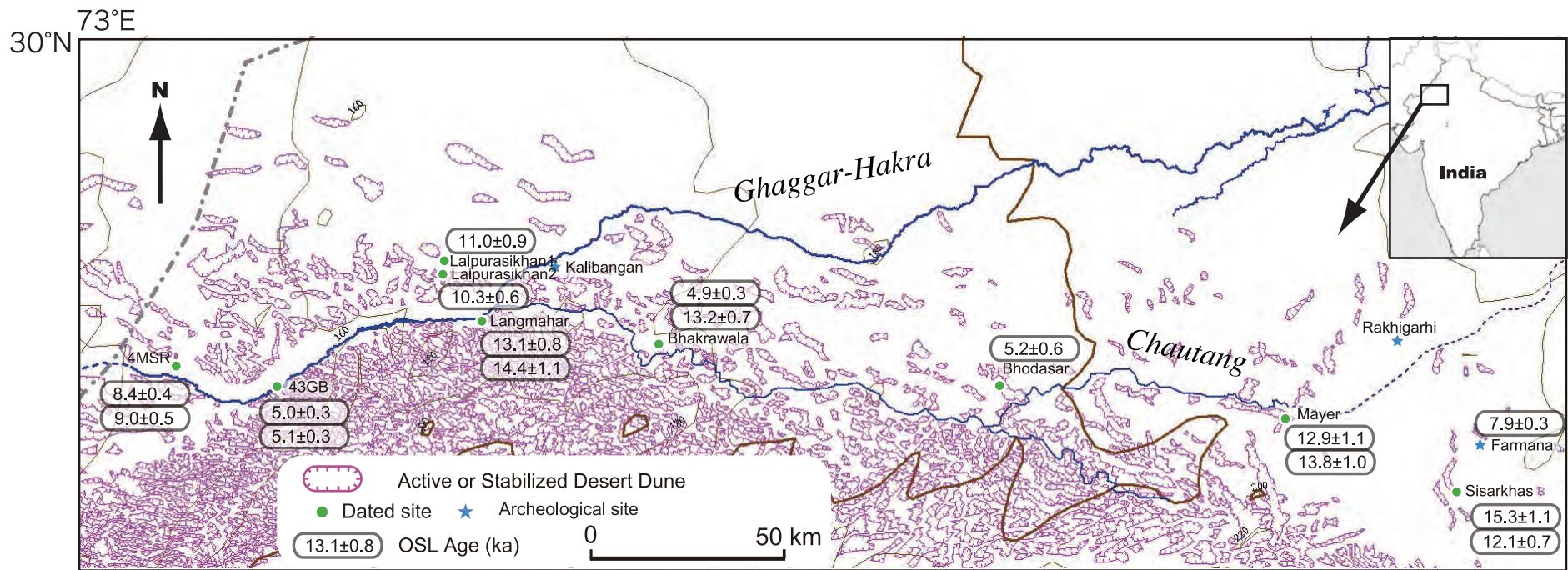


Figure 1 Shitaoka et al.

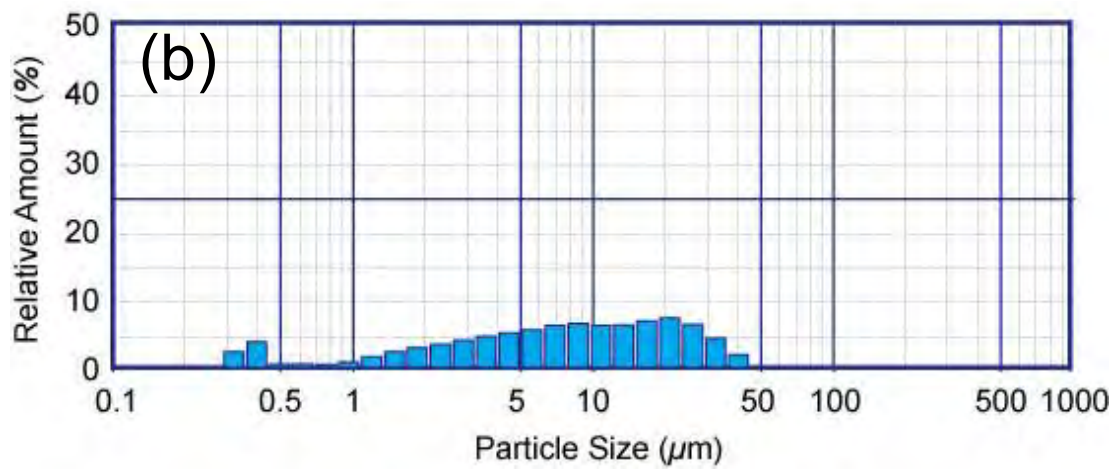
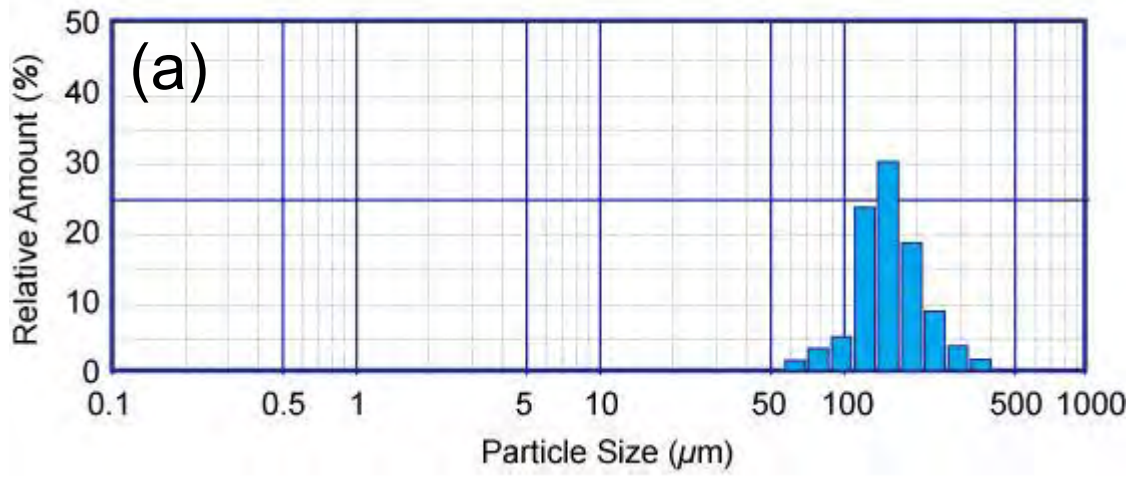


Figure 2 Shitaoka *et al.*

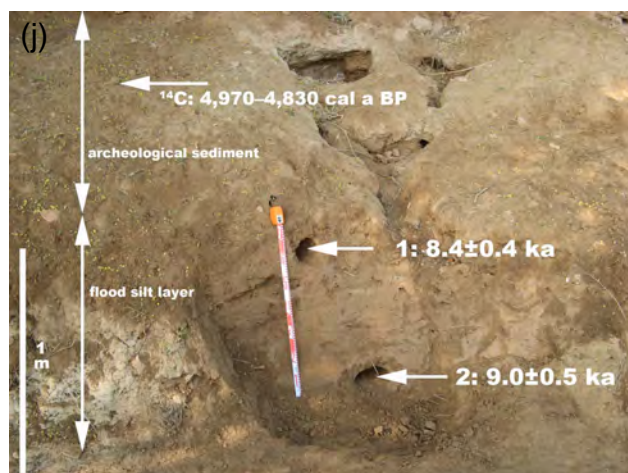
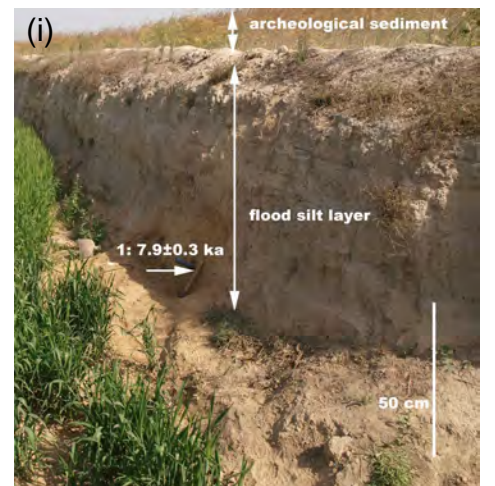
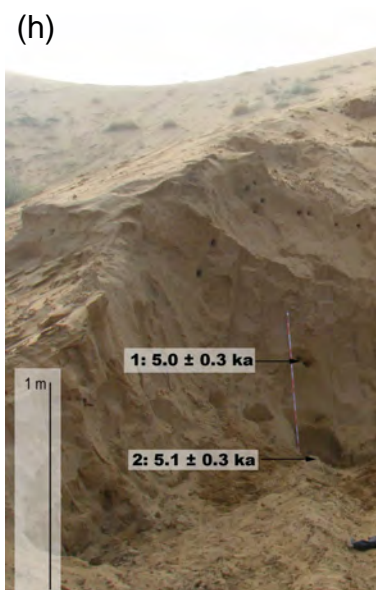
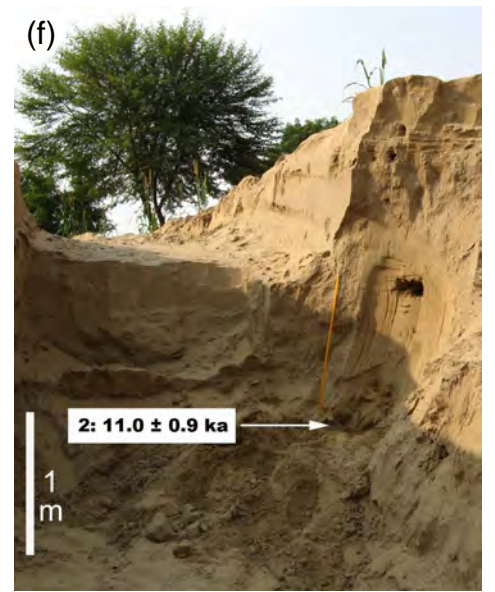
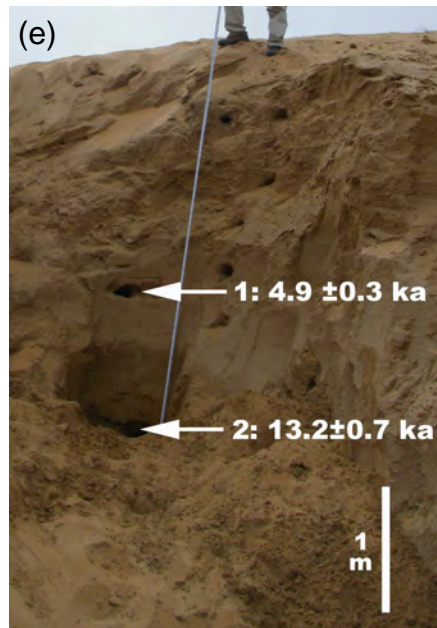
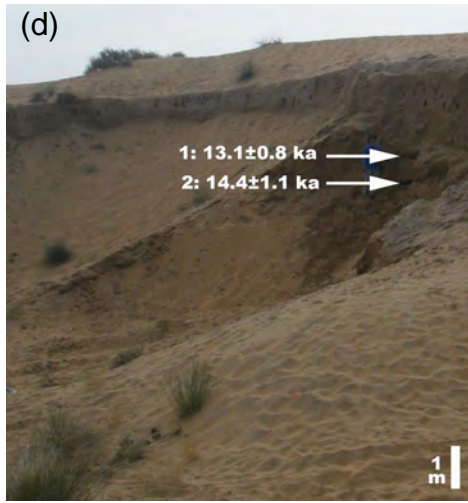
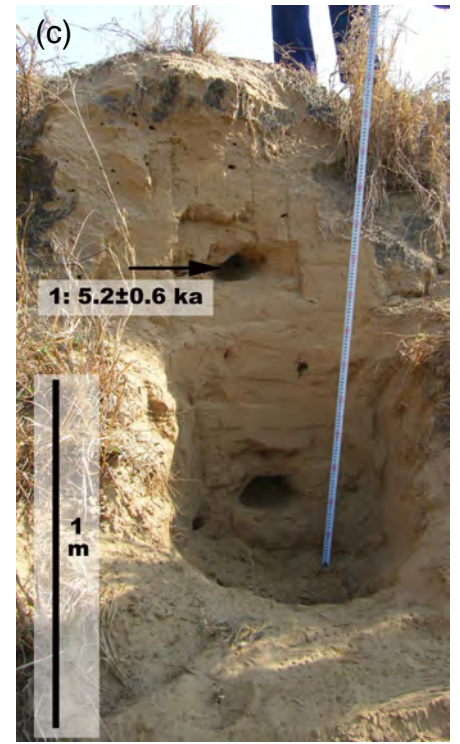
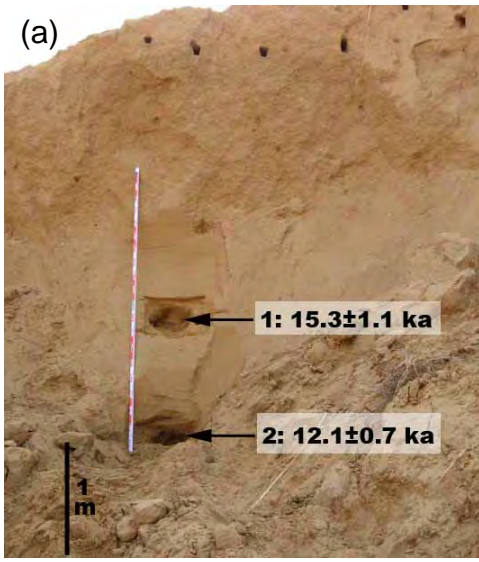


Figure 3 Shitaoka et al.

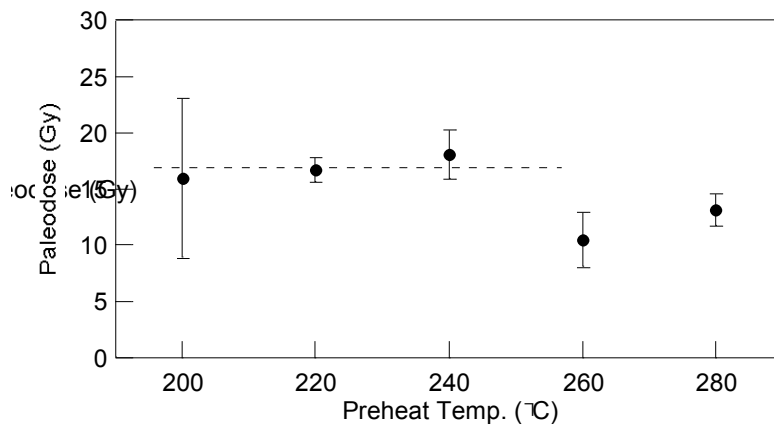


Figure 4 Shitaoka *et al.*

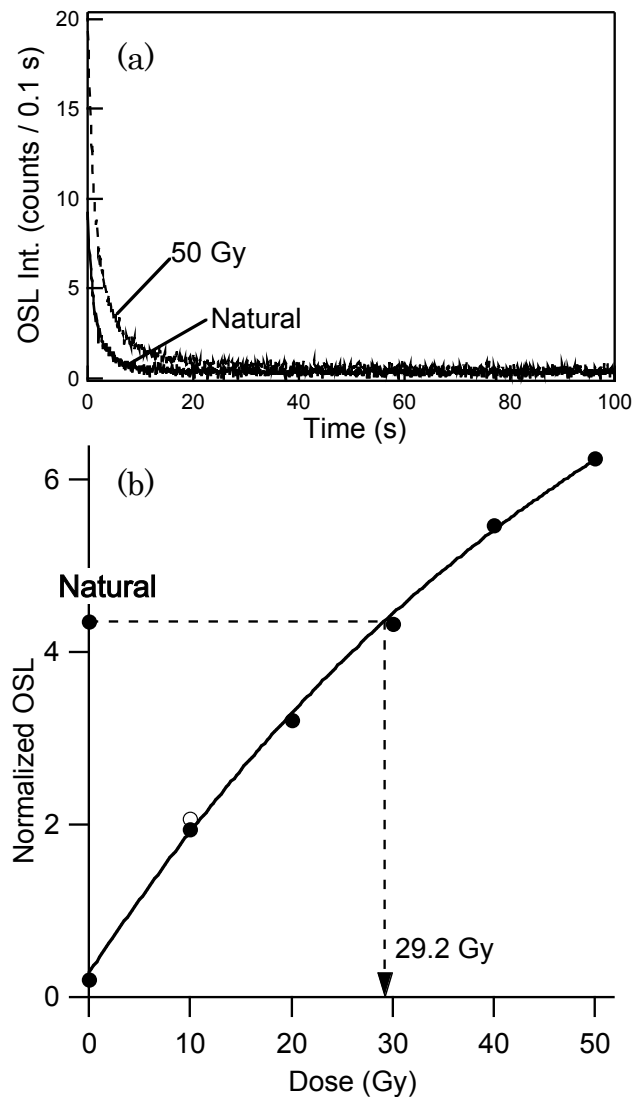


Figure 5 Shitaoka *et al.*

Step	Treatment	Observed
1 ^(a)	Give dose, D_i	-
2	Preheat (230°C for 60 s)	-
3	Stimulate for 100 s at 120°C	L_i
4	Give test dose, 3 Gy	-
5	Cut heat (160°C)	-
6	Stimulate for 100 s at 120°C	T_i
7	Return to 1	-

(a) Step1: For the natural sample, $i = 0$ and $D_0 = 0$ Gy.

Table 1 Shitaoka *et al.*

Sampling location	Sample No.	Paleodose (Gy)	Aliquots	U (ppm)	Th (ppm)	K (wt %)	Annual dose (mGy/a)	OSL age (ka)
Sisarkhas	1	38.3±2.5	11	1.78	10.68	1.22	2.50±0.08	15.3±1.1
	2	32.0±1.6	18	1.75	11.59	1.28	2.66±0.09	12.1±0.7
Maiyer	1	30.2±2.2	11	1.64	10.95	1.00	2.34±0.10	12.9±1.1
	2	34.1±2.0	9	1.80	12.06	1.03	2.47±0.09	13.8±1.0
Bhodasar	1	13.4±1.0	3	1.79	10.80	1.19	2.57±0.25	5.2±0.6
Rangmahal	1	26.4±1.3	11	1.05	7.97	1.08	2.01±0.08	13.1±0.8
	2	34.1±2.3	9	1.49	9.97	1.21	2.37±0.08	14.4±1.1
Bhakrawala	1	11.2±0.4	23	1.50	11.28	0.98	2.27±0.09	4.9±0.3
	2	28.2±1.1	27	1.59	9.77	0.99	2.14±0.07	13.2±0.7
Lal Pura Sikhan-1	2	33.4±2.3	13	2.62	12.82	1.37	3.03±0.11	11.0±0.9
Lal Pura Sikhan-2	2	32.4±1.7	12	2.77	13.97	1.51	3.15±0.09	10.3±0.6
43GB	1	11.7±0.7	20	1.51	8.98	1.21	2.33±0.08	5.0±0.3
	2	11.5±0.6	30	1.42	9.44	1.15	2.23±0.08	5.1±0.3
Farmana	1	46.9±1.5	18	5.70	28.15	2.31	5.95±0.16	7.9±0.3
4MSR	1	23.9±1.0	22	2.46	12.43	1.58	2.83±0.08	8.4±0.4
	2	25.4±1.1	26	2.67	13.12	1.55	2.81±0.08	9.0±0.5
Samples of Farmana and 4MSR are flood silt. Others are paleo-dune sand.								

Table 2 Shitaoka *et al.*