Optical age estimates for hyper-arid fluvial deposits at Homeb, Namibia

M.C. Bourke*, A. Child, S. Stokes

School of Geography and the Environment, University of Oxford, Oxford, OX1 3TB, UK

Abstract

Two 25 m sequences of slack water facies sediments have been dated in the Kuiseb River in Namibia by optical dating of sand-sized quartz grains. The eight samples indicate the sediments were deposited between 6.3 and 9.8 ka. This revises previous age estimates for the Homeb Silts. According to our criteria, six out of eight samples displayed characteristics of partial bleaching. This result was not unexpected as arid fluvial systems have high suspended sediment concentrations, short flow durations and a tendency for flow peaks to occur at night.

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1. Introduction

Determining the age of fluvial sediments in arid regions utilizing traditional methods such as ^{14}C has been hampered by the low abundance of organic material. In recent years, the successful application of luminescence techniques to fluvial facies has resulted in an unprecedented advance in our ability to determine the chronology of past phases of geomorphic activity and consequent paleoclimatic inferences (e.g., Colls, 1999; Wallinga, 2001; Stokes and Walling, 2002). Here we apply optical dating to a suite of fluvial sediments at Homeb on the Kuiseb River in Namibia (Fig. 1) in order to assess the suitability of the method for use in hyper-arid fluvial systems, and to re-examine the accuracy of the currently held age estimate.

Two dating techniques have previously been used to determine the age of the Homeb Silt Formation. Vogel (1982) radiocarbon dated gastropod shells, wood fragment and thin calcareous crusts, and derived ages between 23,000 and 19,000 ^{14}C-years BP. Eitel and Zoller (1996) used thermoluminescence on two samples that bracket the silt formation and determined an age of $20,300 \pm 3200$ a and $19,300 \pm 1800$ a. This places the aggradation phase just prior to the peak of the Last Glacial Maximum—a period of enhanced aridity in the region (e.g., Goudie, 2002) when fluvial activity is assumed to be minimal.

*Corresponding author.

E-mail address: mary.bourke@geog.ox.ac.uk (M.C. Bourke).

2. Dating of fluvial sediments in arid environments

Dating of fluvial sediments utilizing luminescence can be problematic. Inherent is the assumption of complete bleaching of the sediment prior to deposition. In fluvial systems this may be difficult to achieve. Optical dating has been used in preference to Thermoluminescence dating as the trapped charges associated with the optically stimulated luminescence (OSL) signal takes significantly less time to reset (Godfrey-Smith et al., 1988; Rendell et al., 1994). There are three important characteristics of arid streams that may negatively influence bleaching trends. They are: low flow duration, high turbidity, and the propensity for flow peaks to occur at night.

The attenuation of UV as it passes through water may reduce the bleaching potential of entrained sediment (Fuller et al., 1994). Turbidity induced by high levels of suspended sediment may further inhibit the bleaching process. Laboratory simulations on relatively low sediment concentrations ($> 0.05\,\mathrm{g\,l^{-1}}$) have demonstrated low bleaching rates and suggest long periods of entrainment are required ($> 20\,\mathrm{h}$) (Ditlefsen, 1992). As many flows in desert streams tend to have low durations and high suspended sediment concentrations (30–50 g $\mathrm{l^{-1}}$ and may exceed $100\,\mathrm{g\,l^{-1}}$) (Tooth, 2000), these conditions may not be easily met. In addition, flows may occur at night. Data from 144 flow events in the Todd River in semi-arid central Australia indicate that 59% of the flow peaks occur during subdued ambient light or darkness (8 p.m.–8 a.m.) (Fig. 3). This tendency for
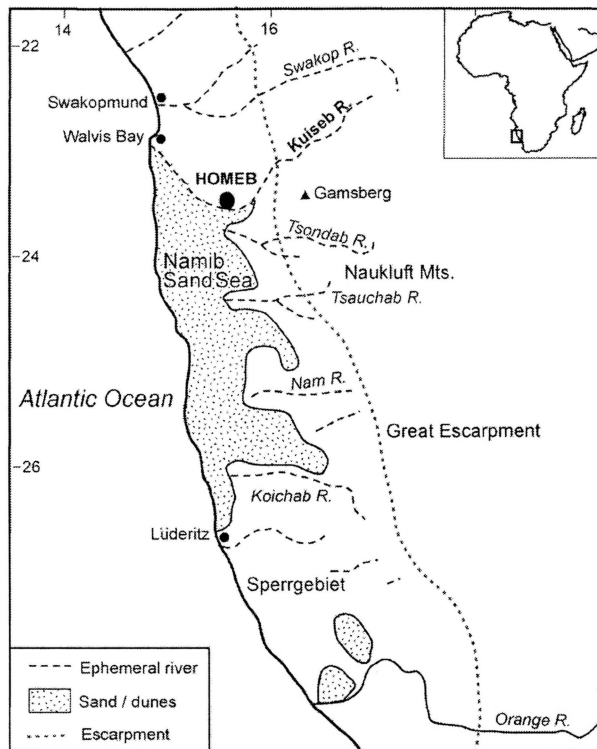
Fig. 1. Location of the sampling site at Homeb in Namibia.

Fig. 2. Field sketch of Homeb silts at Site 1. Location of samples 2–6 are shown.

floods to occur at night removes any potential for bleaching during entrainment.

Recent progress in luminescence methodology has seen an increase in the successful application of the technique to fluvial environments (Stokes and Walling, 2002) and optical dating has been successfully applied to many arid systems and indeed to slack water facies (e.g., Kale et al., 2000). This suggests that long periods of exposure to UV, and the tendency towards Hortonian overland flow on contributing slopes, are important components of the bleaching cycle in arid fluvial systems. However, there is a high probability that arid fluvial samples will contain a mixture of well bleached and partially bleached sediments. Tests for incomplete bleaching are therefore an essential component of the dating protocol.

3. Study area: the Homeb silts

The Kuiseb River canyon runs east to west along the northern margin of the Namib Sand Sea (Fig. 1). The Homeb Silt Formation is located along 62 km of the Kuiseb River between Gomkaeb and Soutrivier and is preserved in protected embayments flanking the channel (Ward, 1987). The Homeb silts have been variously described as lacustrine sediments emplaced behind an aeolian dune dam (e.g., Goudie, 1972), valley fill (e.g.,
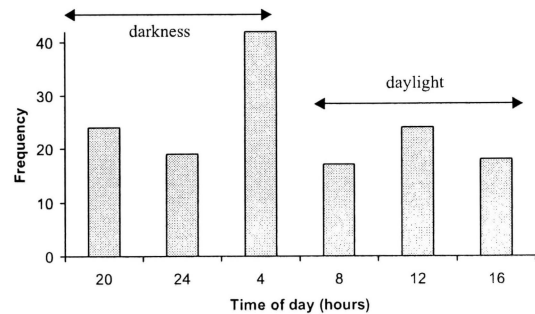
Ollier, 1977; Smith et al., 1993) and slack water deposits (Heine and Heine, 2002). Sedimentary descriptions (Smith et al., 1993) have determined that they were predominantly deposited from suspension. The transport of the sediments close to the top of the water column suggests a higher likelihood of being well bleached relative to bedload facies (Fuller et al., 1994).

4. Methodology

4.1. Sample sites

Eight samples were taken from two sites at the Homeb settlement on the Kuiseb River. The first site (Fig. 2) is a 25 m high vertical stack of interbedded mud and sand deposited predominantly in a slack water environment. The second site is located in a tributary close to the junction upstream of Site 1. The top of the sediment stacks are approximately 45 m above the present channel bed.

4.2. Age determination

The dose rate was determined in the field using a Harwell-Nutmaq 4-channel NaI gamma-spectrometer. In the laboratory, the samples were unpacked under subdued amber lighting and 2–3 cm of sediment was removed from each end of the tubes. Preparation involved carbonate removal using 10% HCl, wet sieving to isolate 90–150 μm quartz grains, heavy liquid separation in order to isolate quartz and feldspars from heavy minerals, and HF (48%) etching was finally used for one hour to remove remaining minerals other than quartz. A monolayer of prepared quartz was mounted on steel discs (10 mm diameter × 1 mm thick) using a silicone oil spray.

Luminescence measurements were made on an automated TL/OSL DA-15 RISØ system. Aliquots were stimulated with 470 nm light from a blue diode. The subsequent OSL emissions were filtered using two 3 mm
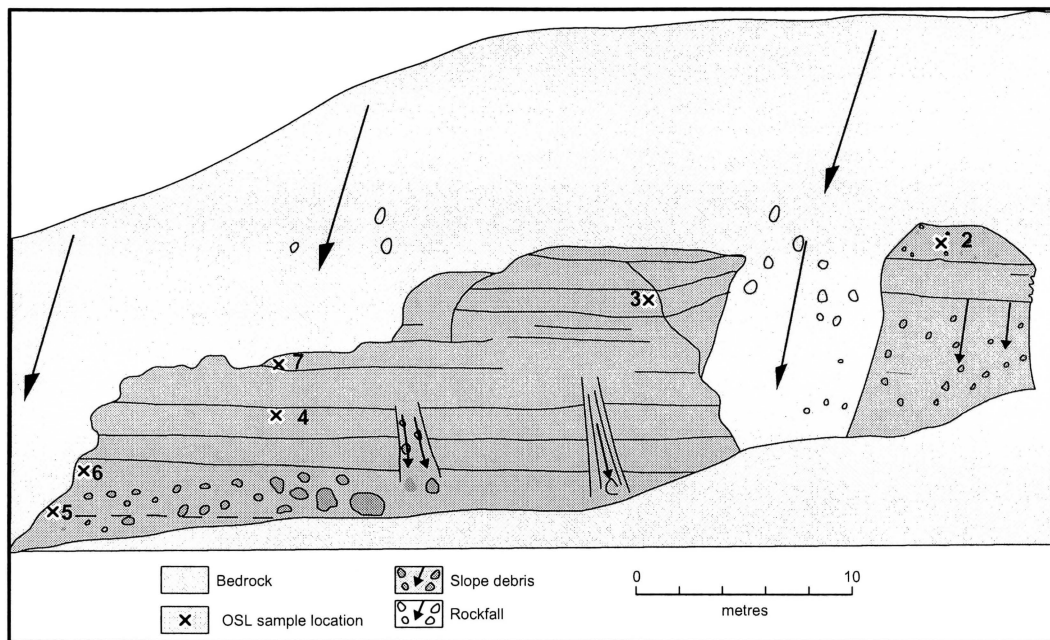
Fig. 3. Histogram indicating the timing of flood peaks for all flow events ($n = 144$) between 15/6/1973 and 21/4/2000 on the arid Todd River in central Australia.

thick U-340 filters (transmission at 340 ± 20 nm), and detected using an Electron Tube 9635Q photomultiplier. All OSL measurements were made at 130°C.

The single aliquot regeneration (SAR) procedure was used (Murray and Wintle, 2000). In our analysis we employed an initial pre-heat of 260°C for 10 s and a preheat of 220°C for 10 s following each of the (ca 2 Gy) test doses. Six independent D_e estimates were determined for each sample (Fig. 4).

4.3. Bleaching analysis

Two techniques were used to assess the extent of partial bleaching. The first uses the relationship between D_e and natural luminescence intensity. Incomplete bleaching leaves some grains with a large remnant dose. The natural luminescence intensity will be high for these grains and the D_e in excess of the D_e corresponding to the burial dose. Grains with high sensitivity to environmental radiation but no pre-deposition dose will exhibit high intensity but have no associated high D_e when compared to equally well-bleached grains of lower sensitivity. A partially bleached sample set will thus produce a trend of D_e increasing with intensity across a range of aliquots (Colls, 1999). A sample containing equally well-bleached grains will exhibit consistent D_es despite differences in intensity. The Pearson's correlation coefficient (R^2) of the D_e vs. intensity relationship is used to derive a value t that is compared to Student's t
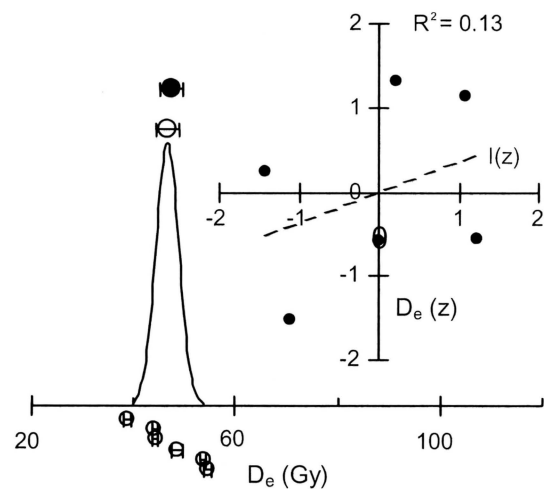
Summary Statistics[a]	
D_e (Gy) Mean$_{wtd}$	46.8 ± 0.27
D_e (Gy) Mean$_{unwtd}$	47.4 ± 5.6
Minimum D_e (Gy)	38.9
Median D_e (Gy)	46.5

Fig. 4. Summary data of sample 4 SAR analysis for the Kuiseb River fluvial samples at Homeb, Namibia. The main plot comprises the individual single aliquot estimates (in open circles and plotted below the x-axis) and an unweighted sample mean (filled circle above the x-axis) and associated distribution. Inset diagrams are standardised plots of the equivalent dose ($D_e(z)$) versus aliquot intensity ($I(z)$). [a]Summary statistics: Mean$_{wtd}$ = weighted mean, Mean$_{unwtd}$ = unweighted mean.

tables (Colls, 1999). A significant relationship indicates variance in the D_es that may indicate partial bleaching (Table 1).

The second technique also assumes that a spread of D_e estimates from aliquots of a given sample is indicative of inconsistent bleaching histories for different grains of a sample (Clarke, 1996). Standard deviation (SD) of a D_e dataset indicates spread. Remnant dose however remains constant throughout burial; therefore, its relative contribution to an accumulating dose decreases with time. Dividing the SD by the dataset's mean produces the 'coefficient of variation' (CV), which represents the relative contribution of the original remnant dose to the contemporary signal. Clarke (1996) uses a SD of 5 Gy and S_n of 0.1 below which a sample is defined as well bleached (Table 1).

Table 1
Results of bleaching analysis

Following Colls (1999)				Following Clarke (1996)		
Sample	t_{calc}	t_{tab}	Well bleached?	SD	S_n	Bleaching extent
1	1.06	2.78	Yes	4.48	0.14	WB
2	3.09	2.78	No	5.82	0.17	PB
3	0.78	2.78	Yes	6.37	0.12	MPB
4	0.78	2.78	Yes	6.09	0.13	MPB
5	0.24	2.78	Yes	3.32	0.096	WB
6	0.58	2.78	Yes	5.95	0.11	MPB
7	0.19	2.78	Yes	6.47	0.15	MPB
8	0.85	2.78	Yes	5.92	0.11	MPB

For the D_e spread analysis (Colls, 1999), the R and R^2 (Pearson's correlation coefficient of the linear least-squares regression plot of paleodose vs. intensity) are used to derive t_{calc}. Where $t_{calc} > t_{tab}$, the relationship is statistically significant and the sample is poorly bleached.
Clarke (1996) defines the following threshold values of standard deviation (SD) and coefficient of variation (S_n) to differentiate well and poorly bleached samples. SD: <5 Gy = well bleached; In samples with a SD > 5 Gy (i.e. samples 2–4 and 6–8) where S_n > 0.1 = poorly bleached. WB = well bleached; PB = poorly bleached; MPB = moderately poorly bleached.

To account for partial bleaching, a minimum age model can be used (Olley et al., 1998). Selection of lowest D_e aliquots picks out the aliquots with the least contribution from the incompletely bleached grain minority.

5. Results

Measurement of the dose accumulated in samples was interpolated from SAR growth curves using the natural luminescence signal for each aliquot. Both bleaching analysis techniques indicate that sample 5 was well bleached prior to burial. Although analysis of the relationship between D_e and luminescence intensity suggests that seven out of the eight samples are well bleached, D_e spread analysis indicates that only two of the samples were well bleached (samples 1 and 5). Samples 3–4 and 6–8 were moderately poorly bleached and sample 2 was poorly bleached. The results indicate that the mean age for samples 1 and 5 can be considered reliable, but that mean age estimates for the remaining samples possibly overestimate the true age. As such, we have adopted a minimum age model for six of the eight Homeb samples given the likely presence of partial bleaching. The proposed ages for samples are indicated in bold in Table 2.

The consistency of age estimations, both for different aliquots of individual samples (e.g., Fig. 4), and across all eight samples, lends confidence to the results. Individual aliquot ages lie between 6.3 and 12.9 ka, and the proposed ages have an age range of 6.3 to 9.8 ka.

The ability to attribute an age to deposits exhibiting partial bleaching, here confirms indications from previous studies of fluvial systems (Murray et al., 1995; Olley et al., 1998, 1999; Colls et al., 2001; Stokes et al., 2001). This illustrates the potential of the technique in arid fluvial environments, even if transport conditions are not favourable for bleaching, the grains giving the

Table 2
Summary of optical dating results

Sample/ section	Height from top (m)	Dose rate (Gy ka^{-1})	Mean D_e (Gy)	Lowest aliquot D_e (Gy)	Highest aliquot D_e (Gy)	Age using minimum aliquot (ka)	Age using mean (ka)	Age using maximum aliquot (ka)
2/1	0.38	3.98 ± 0.07	34.40 ± 5.30	25.05 ± 0.45	40.75 ± 0.62	**6.30 ± 0.16**	8.43 ± 1.34	10.25 ± 0.24
3/1	3.46	5.06 ± 0.07	51.17 ± 5.80	42.68 ± 0.43	60.11 ± 0.62	**8.44 ± 0.15**	9.89 ± 1.16	11.89 ± 0.21
7/1	9.40	3.89 ± 0.07	43.85 ± 5.90	33.69 ± 0.54	50.26 ± 0.67	**8.66 ± 0.22**	10.88 ± 1.53	12.93 ± 0.30
4/1	12.65	4.92 ± 0.08	47.41 ± 5.60	38.95 ± 0.72	54.69 ± 0.77	**7.91 ± 0.19**	9.51 ± 1.15	11.11 ± 0.23
6/1	16.16	4.95 ± 0.08	55.10 ± 5.40	48.46 ± 0.51	63.19 ± 0.68	**9.79 ± 0.19**	11.05 ± 1.11	12.77 ± 0.25
5/1	19.44	3.59 ± 0.06	34.76 ± 3.00	29.95 ± 0.23	39.75 ± 0.38	8.34 ± 0.15	**9.36 ± 0.85**	11.07 ± 0.21
1/2	—	3.61 ± 0.06	32.75 ± 4.10	28.21 ± 0.63	39.94 ± 0.76	7.83 ± 0.22	**8.93 ± 1.15**	11.08 ± 0.28
8/2	—	5.49 ± 0.08	51.87 ± 5.40	43.04 ± 0.45	56.95 ± 0.67	**7.84 ± 0.15**	9.31 ± 0.99	10.38 ± 0.20

A minimum age model for samples 2–4 and 6–8 is recommended as these samples were poorly bleached (Table 1). Proposed ages for Homeb silts are indicated in bold.