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A Test Study of Luminescence Dating of Fluvial Sediments from Bangladesh

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Abstract

In a test study on two samples taken from young overbank deposits near the confluence of the Jamuna and Padma rivers of Bangladesh, grain size and heavy minerals were analysed and infrared simulated luminescence (IRSL) ages were calculated. In both the samples, composed of mainly fine sands and silts, the green and brown amphiboles dominate with more than 50% followed by zoisite. The amount of metamorphic and opaque components is very low. The sediments were possibly derived from a complex source dominated by low to high rank metamorphic and recycled sedimentary source. The IRSL dating results show that the sediments were deposited about 800-900 yr BP, which is consistent with the geological expectations. The thermoluminescence (TL) ages determined for the same samples are significantly overestimated due to incomplete bleaching of the TL signal prior to deposition. A systematic application of IRSL will, however, allow to establish a reliable chronological frame for the Quaternary sequences of Bangladesh and may lead to a better understanding of changing fluvial dynamics in the Padma-Jamuna river system.

সারাংশ

যমুনা এবং পদ্মা নদীর সংযোগস্থলের নদী পাড় থেকে নিকট অতীতে জমা হওয়া পললের নমুনা সংগ্রহ করা হয়। এসব নমুনার দানার মাপ, ভারী-মনিকের বিশ্লেষণ এবং ইনফ্রারেড স্টিমুলেটেড লুমিনেসেন্স (আই.আর.এস.এল.)-এর মাধ্যমে বয়স নির্ধারণ করা হয়েছে। সংগৃহীত দু'টো নমুনাই মিহি বালু ও সিল্ট দিয়ে তৈরি। সবুজ ও খয়েরী এম্ফিবোলসমূহ ভারী মনিক হিসেবে প্রধান এবং এদের ভেতর জোয়েসাইট ৫০%-এর বেশি। রূপান্তরিত ওপাক অংশের পরিমাণ খুব কম। পললসমূহে সম্ভবতঃ একাধিক উৎপত্তিস্থান বিদ্যমান, যার কোনো কোনোটি একাধিক মানের রূপান্তরিত শিলা এবং একাধিক পলল চক্রের মাধ্যমে জমাকৃত পাললিক শিলা থেকে উৎপন্ন। আই.আর.এস.এল. বিশ্লেষণের মাধ্যমে দেখা যায় যে, পললসমূহ সম্ভবতঃ ৮০০-৯০০ বছর পূর্বে জমা হয়েছিল। নমুনাসমূহের এ বয়স তাদের ভূতাত্ত্বিক প্রেক্ষাপটের সাথে সামঞ্জস্যপূর্ণ। একই নমুনাসমূহের থার্মোলুমিনিসেন্স পদ্ধতির মাধ্যমে নির্ণীত বয়স অনেক বেশি। টি.এল. সিগন্যালের অসম্পূর্ণ ব্লিচিং-এর প্রধান কারণ। নদী বাহিত পললে অসম্পূর্ণ ব্লিচিং একটি সাধারণ বিষয়। অতএব, বাংলাদেশের কোয়াটারনারী পললসমূহের যথাযথ বিশ্লেষণের ক্ষেত্রে আই.আর.এস.এল. পদ্ধতি একটি গুরুত্বপূর্ণ ভূমিকা রাখতে পারে।

Introduction

Climate variations during the Quaternary Period have caused significant changes in terrestrial environments. In southern Asia, periods of higher humidity or aridity originate from changes in monsoon intensity. During times of widespread glaciation at higher latitudes, monsoon intensity was generally lower than today (*e.g.* Duplessy 1982 and

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Andrews *et al.* 1998). Higher precipitation rates have been recognised during early to mid-Holocene times (McClure 1976 and Bryson & Swain 1981). Evidence for wet climatic conditions during the Eemian has been given as well (Burns *et al.* 1998). It is reasonable that these phases of increased precipitation must be reflected by response in fluvial systems. Periods of intense rainfalls should have triggered a series of flooding events in areas downstream, like Bangladesh. Investigation of fluvial activity in the past may thus provide further information about monsoon variability and naturally occurring climate change. However, any kind of paleoclimate reconstruction needs reliable chronological framework. The luminescence methods allow the dating of sediment deposition ages back to some hundred or even thousand years. It might thus be an indispensable tool for the reconstruction of fluvial systems history. Nevertheless, for some depositional environments zeroing of the luminescence signal prior to deposition, the pre-requisite for dating, is not met. This study on the Holocene over-bank deposits was carried out to test if these kind of sediments from Bangladesh are suitable for luminescence dating.

Geological Setting

Investigation was carried out on fine grained over-bank deposits at the confluence of the Jamuna (Brahmaputra) and Padma (Ganges) rivers in Bangladesh (Fig. 1). The Jamuna originates from the northeastern Himalayas (Tibet) and flows through India (Assam) before entering Bangladesh and merges the Padma near the village of Aricha. After some 100 km the Padma debouches into the smaller Meghna river running south to the Bay of Bengal.

Due to monsoon circulation the low flows during the dry winter period and the high flows during the summer monsoon occur from July till September. These times of intense precipitation are frequently joined by massive flooding events. On average, the river sediment load consists of about 75% silt, 20% sand and less than 5% clay. Most of this material is supplied by weathering from the Himalayan mountain ranges and reworked fluvial in-fill of the Assam valley, India. The River Jamuna is an example of a large sand-bed braided river characterised by sand bars of various size, laterally migrating due to seasonally occurring floods. In the multi-channel Jamuna system, transitions from braided to anastomosing and meandering can be observed (Bristow 1993). A morphological study with special respect to the evolution of channels, bars and banks was given by Thorne *et al.* (1993). The maximum channel depth is 40 m, the mean depth about 5 m (Bristow 1993), which is of prominent importance for bleaching processes during transport in terms of luminescence dating. Following the fundamental work of Coleman (1969) further sedimentological studies were published by Bristow (1987 & 1993), Klaassen & Vermeer (1988) and Huq *et al.* (1997), setting up a new facies model for the sand bars of the Jamuna reach under consideration here.

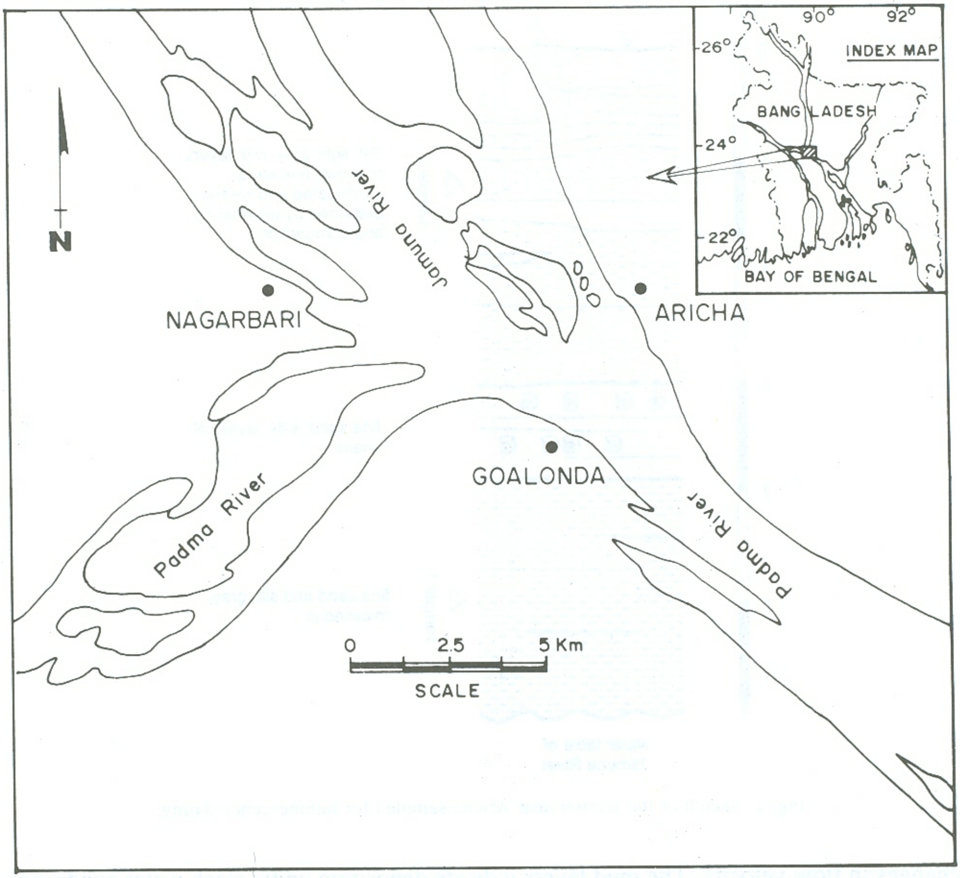

Fig. 1. Map of the Jamun/Padma delta in Bangladesh showing the sample location at the confluence of both the rivers near Aricha.

The Sampled Material

The sampling site near Aricha is situated at the left bank of the Jamuna river belonging to the old Padma-Jamuna floodplain. The samples for dating and additional investigations described below were recovered in a succession of plane bed laminated sand and overlying over-bank deposits (Fig. 2). Sample 1 was taken from a 2 m thick bed of micaceous fine sand and silt of greyish colour caused by high water content (gleyification) from a depth of about 5 m. This more or less parallel laminated bed can be interpreted as bar top sediment documenting vertical accretion. This type of sedimentation is considered to be typical for this reach of the river (Bristow 1993: 284, Alam 1996: 37). The sand and silt were transported at high suspended sediment concentration in the water flow controlling the bleaching state for luminescence.

Sample 2 was recovered from the overlying bed from a depth of about 1.25 m composed of alternating layers of light fine sand and grey silt and clay mirroring rapid

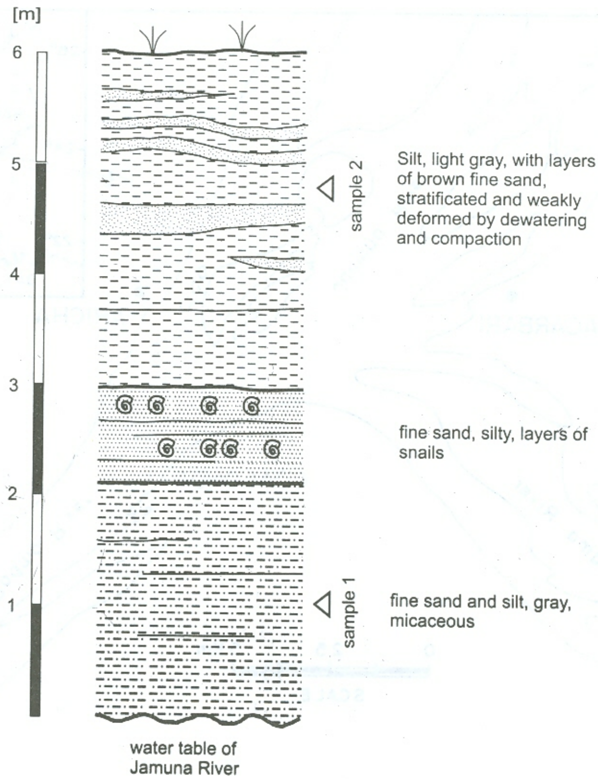

Fig. 2. Sketch of the section near Aricha sampled for luminescence dating.

changes in flow velocity. The mud layers indicate deposition under slack water conditions. The 3 m thick bedset is slightly deformed by dewatering and differential compaction.

Heavy mineral analyses of both the samples were carried out for identification of the sediment source area. The sediments having grain-size < 0.2 mm were treated with hydrochloric acid in order to remove carbonates. Heavy minerals were subsequently separated by centrifuging using Sodium-Polytungstate (d = 2.8 g/cm^3). After embedding in Meltmount (^{TM}Cargille Labs) the heavy mineral fraction was analysed under a polarising microscope. In both the samples green and brown amphiboles are dominating with more than 50% followed by zoisite of about 18% (Table 1). The grain size in sample 2 is quite smaller (0.05-0.1 mm) than the one in sample 1 (0.1-0.2 mm), obviously influencing the contents of Zircon which is significantly higher in sample 2. The rounded shapes of all zircons indicate long distance transport; whereas, most of the other grains display fresh crystal surfaces indicating short distance travel. The amount of metamorphic (sillimanite, kyanite) and opaque components (ore, spinel) are very low (=1% each).

Table 1. Heavy mineral composition of the investigated samples (%).

Sample	Garnet	Amphibole	Zoisite	Met. Minerals	Zircon	Tourmaline	Other Stable Min.
2	5.5	54.5	18.2	1.8	14.5	4.5	0.9
1	2.9	68.3	19.2	1.0	4.8	2.9	1.0

The heavy mineral assemblages in the samples indicate that the sediments were derived from a complex source dominated by low to high rank metamorphic and recycled sedimentary sources. In particular, mafic rocks are believed to play important role as reflected by the contents of amphiboles (green and brown varieties) and zoisite.

Luminescence Dating

A short overview of the principles and some methodological aspects of luminescence dating is given below. More detailed reviews have just been provided by *eg.* Duller (1996), Prescott & Roberstson (1997), Wintle (1997) and Aitken (1998).

The dating of sediments by luminescence is based on radiation damage in minerals caused by naturally occurring radioactivity. The radioactivity originates from the decay of elements within the ^{232}Th and ^{238}U decay chains, from the decay of ^{40}K and from cosmic rays. The contribution of other radio-isotopes like ^{14}C and ^{87}Rb is negligible. The radiation results in excitation of electrons, which are captured at electron traps within the crystal lattice. A given amount of stimulation energy, light or heat, causes the trapped electron to recombine by instantaneously emitting a photon. These photons, the luminescence signal, are thus a measure of the amount of trapped electrons. When minerals are exposed to sunlight during sediment transport, the electrons start to retrap due to the energy induced by light. During burial times, when the minerals are sealed from daylight, the amount of trapped electrons increases proportionally to the radioactivity within the sediment. The intensity of radioactive rays within the sediment is called the dose rate. The amount of radiation damage (trapped electrons), called the equivalent dose (ED), is quantified by a measurement based on the comparison of natural and artificial irradiated sub-samples. The luminescence age of a sample is calculated by the equation:

$$\text{Age (yr)} = \frac{\text{equivalent dose (Gy)}}{\text{dose rate (Gy yr}^{-1})}$$

For dating of sediments, it is essential that the luminescence signal is set to zero prior to deposition. Incompletely bleached sediments, where some old luminescence is still remaining, will result in apparent higher age estimates (Fig. 3). The time needed for

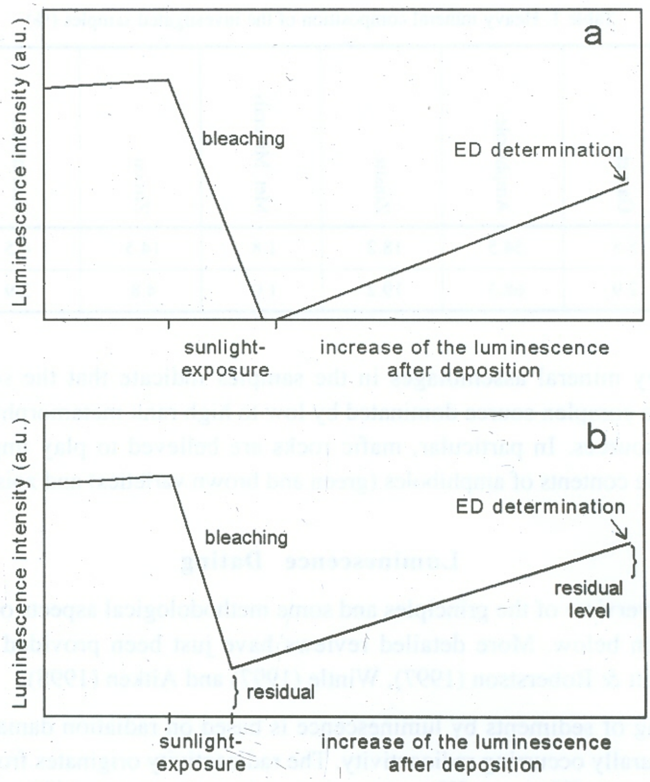

Fig. 3. Schematic sketch showing the principles of complete (a) and partial (b) bleaching. The luminescence is bleached during exposure of the sediment grains to sunlight. After deposition luminescence starts increasing again. A residual luminescence will remain (b) when the time of sunlight exposure was too short to allow zeroing. This residual signal causes age overestimation when dating incompletely bleached sediments.

zeroing depends on the light intensity, in fluvial environments mainly controlled by turbidity within the water column and, additionally, by water depth and turbulence (Ditlefsen 1992). For the high flood deposits from the Jamuna/Padma system, zeroing of the luminescence prior to deposition will be mainly crucial due to the high amount of suspended sediment grains within the water column. It is, therefore, essential to investigate if the luminescence signal used for dating was set to zero prior to deposition. Several methods to test for incompletely bleached sediments have been discussed by Li (1994), Duller *et al.* (1995), Aitken (1998) and Preusser *et al.* (2001).

Methodological Aspects

For this first test study on dating fluvial sediments from Bangladesh, a multiple aliquots approach on polymineral fine-grains was used. Samples were treated with hydrochloric acid and hydrogen peroxide to remove carbonates and organic matter. The fraction 4-11 μm was enriched using the procedures described by Frechen *et al.* (1996). Batches of 45 aliquots were prepared and irradiated using a ^{60}Co source. After storage at room temperature for four weeks, the samples were preheated at 150°C for 16 h. A Schott BG39 filter was used during the luminescence measurements. Infrared stimulated luminescence (IRSL) was recorded during a 25 s shine-down of IR-diodes. Subsequently, thermoluminescence (TL) was measured from the same discs. The integral 20-25 s was substracted from the IRSL curves as late-light, representing hard-to-bleach components of the IRSL, scattered light and photomultiplier dark-noise (Aitken & Xie 1992). For the generation of growth curves the integral 0-20 s (IRSL) and the integral 200-450°C (TL) were analysed, respectively. The growth curves were fitted using a single saturating function weighting the points inversely to their variance.

The concentrations of potassium, thorium and uranium were determined by high-resolution gamma spectrometry as described by Preusser (1999a). Cosmic dose rates were estimated considering overburden sediment cover. Dose rates were calculated using an alpha efficiency of 0.07 ± 0.02 and a water content of 35 ± 5%.

Results and Discussion

The results of dose rate determination, ED calculation and resulting ages are given in Table 2. For both samples, the TL ages estimates are significantly higher as for IRSL. Furthermore, The TL shows an increase of the ED with rising temperature (Fig. 4). Both the features indicate insufficient bleaching of the TL prior to deposition. It is well known that resetting of the light sensitive, TL needs several hours, while IRSL is zeroed within a few minutes (Godfrey-Smith *et al.* 1988). Under restricted light conditions, like in shallow water, the time needed for zeroing will increase dramatically (Ditlefsen 1992 and Preusser 1999b). The TL approach used in the present study is, thereforer, thus not suitable for dating these kinds of sediments from Bangladesh.

Table 2. Dosimetric data, dose rates, equivalent dose and resulting luminescence ages.

Sample	K (%)	Th (ppm)	U (ppm)	Dcos (mGy a^{-1})	D (mGy a^{-1})	ED_{IRSL} (Gy)	ED_{TL} (Gy)	Age_{IRSL} (yr)	Age_{TL} (yr)
2	1.94±0.06	15.10±0.45	3.09±0.09	0.11	3.40±0.37	2.90±0.10	42.1±5.7	850±100	12390±2140
1	2.17±0.06	15.89±0.48	3.51±0.11	0.08	3.69±0.40	3.00±0.19	32.1±2.0	810±100	8690±1090

On the other hand, the two IRSL ages are consistent within the error limits. This might indicate complete bleaching of the IRSL prior to the last deposition (Preusser *et. al.* 2001). Additionally, the ED calculated by IRSL does not increase with the time of optical stimulation (Fig. 5). Increasing ED with stimulation time would be evident for incompletely bleached sediments (Singhvi & Lang 1998).

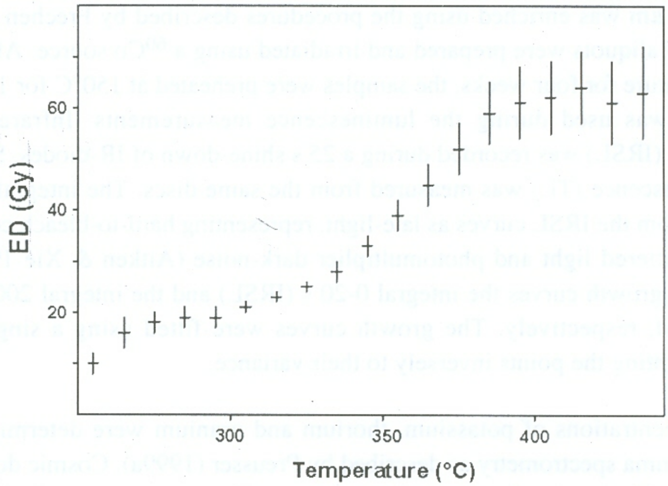

Fig. 4. Plot of equivalent does (ED) versus temperature for thermoluminescence (TL) of the sample 2. The ED's are calculated for 10°C integrals. The ED increases from ≈ 20 Gy for the integral 250-260°C to ≈ 60 Gy for temperatures above 400°C. This increase of ED with temperature gives strong evidence of incomplete bleaching of the TL prior to deposition.

There is yet no independent age control for the samples been dated. However, the geomorphologic situation implies a rather young geological age (less than some thousand years). According to the IRSL results the sediments were deposited about 800-900 yr. ago, thus, corresponding with the estimated age.

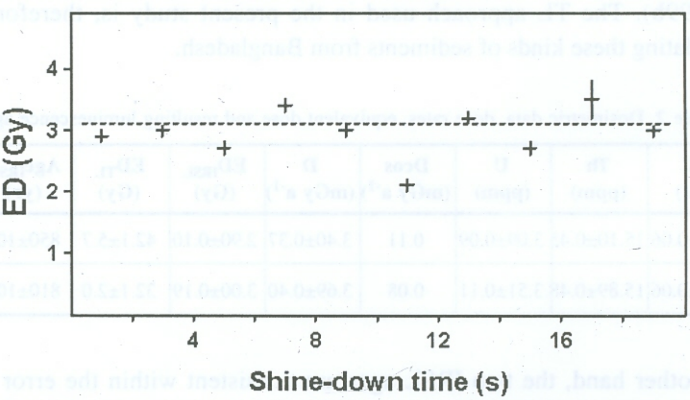

Fig. 5. Plot of equivalent dose (ED) versus shine-down time for infrared stimulated luminescence (IRSL) of the sample 2. The ED's are calculated for 2 s integrals. The dotted line represents the mean value calculated for the integral 0-20 s. The ED values are more or less constant. The scattering is caused by the low counting statistics of the natural IRSL signal.

Conclusions

All indications imply complete bleaching of the IRSL prior to deposition for the over-bank deposits investigated. Hence, IRSL seems to be a promising method for dating fluvial sediments from the Jamuna/Padma delta. It has been demonstrated as well that TL seems to be less suitable and may result in significantly higher ages only. The application of systematic IRSL dating can establish reliable chronological framework for the Quaternary sediments from Bangladesh.

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