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Thermoluminescence Dating (TL) : A Brief Outlook and Applications to the River Terraces of Manipur

S. Bidyaswor Singh

Department of Physics, Thoubal College, Thoubal, Manipur, India

ABSTRACT: Luminescence dating is a leading technique for applications in materials of earth sciences and archaeology. The technique is superior to the carbon dating and useful for dating materials ranging in age from a few decades to around 8,00,000 years. In this paper, first, we present a brief outline of the development of the technique, its basic principles, measurement equipment that is employed in determining age, luminescence properties of minerals used in dating etc. and then the application of the methodology of the technique to the terraces of rivers in the valley of Manipur, India. The study of the terrace ages will contribute a great to the understanding of land formations and reconstruction of environmental change in the valley of Manipur, India.

KEYWORDS: Luminescence dating, Thermoluminescence, Paleodose, Dose rate, Terraces of river.

I. INTRODUCTION

Luminescence dating includes the thermoluminescence (TL) and optically stimulated luminescence (OSL) dating techniques. In TL the sample is heated in a controlled manner and a certain physical property is continuously monitored. [1]. By measuring the variation of the physical parameter as a function of time or sample temperature, one can get important information concerning the processes which take place in the sample during heating [1-3]. Thus, thermally stimulated process is used as one of the most powerful tools of research that can investigate the intrinsic parameters of insulators or semiconductors, amorphous and polycrystalline materials, minerals, ceramic and biological materials like fish scales, bones and dental enamels etc. In OSL the sample is stimulated using a light source of a chosen wavelength.

1.1 Historical Background of TL Dating: Thermoluminescence (TL) dating has emerged as a technique by itself to directly determine the age not only of ancient pottery, bricks and terracotta but also the burial age of the main mineral constituents in unheated Quaternary Sediments. Even since the pioneering work of Farrington Daniels (University of Wisconsin, USA) who in early 1950 suggested the possibility of using TL to date geological and archaeological age [4], the subject has developed into a full fledged actively in many laboratories all over the world. Wintle and Huntley [5,6] were the first to present a workable TL dating technique for determining the time of deposition of sediments. In India TL dating in Geology was initiated by Prof. I.K. Kaul at Indian Institute of Technology Kharagpur [7]. However, TL dating in archaeology started in India in the seventies both at BARC, Bombay and PRL, Ahmedabad. Gotsu *et al.* [8], extended TL dating to materials other than baked clay. This extension, in which burnt flint, was potentially took the method well beyond the age range of radio-carbon dating. The same is true for volcanic lava where reported by Wintle [9] and by Guerin and Valldas [10], but turned out to be rather difficult in practice. Vast amounts of work on other Geological samples has been done over the last 35 years, starting with Morozov [11] who studied the TL from various types of sediments. Berger *et al* [12] have reported TL age for the 4-11 μm polymineral fraction in a suite of loess samples from Newzeland and Alaska that have relatively well constrained independent ages upto nearly 800 Ka. Another accuracy test was done by Huntley *et al.* [13] using nearly 100 μm quartz grains extracted from the stranded bleach-dune sands as old as 800 Ka from South Australia. Setting the TL clock to zero by the bleaching effect of sunlight windblown and some watertain sediments can also be dated [5-6]. Not only this TL has also been utilized for dating meteorites fallen to earth [14-16]. The technique of TL dating has the potential to date objects or events in the time frame of from 50 years to 8×10^5 years.

1.2 Principle of the Luminescence Dating: Natural minerals such as quartz, feldspar, calcite and zircon, which are present in geological and archeological settings, when subjected to ionizing radiation, they are able to store energy in their crystal lattices. The ionizing radiation emanates naturally from the immediate surroundings of the minerals.



Cosmic radiation may also contribute a small component. If the minerals used in dating are stimulated, they release the energy which is proportional to the stored energy. This energy given out by the mineral or dosimeter is referred to as the palaeodose or archaeodose [17]. If we know the rate at which energy was accumulated by the dosimeter, or the dose rate, then the luminescence age is given by

$$Age(ka) = \frac{Palaeodose(Gy)}{Dose\ Rate\ (Gy/ka)}$$

The palaeodose is a combined dose, resulting from exposure to α, β and γ radiation and thus it cannot be measured directly. Therefore, it is determined as an equivalent dose i.e. the amount of artificial dose delivered by irradiation in the laboratory that induces a luminescence signal identical to the natural one in the sample [18].

$$i.e. Age(ka) = \frac{Equivalent\ Dose(Gy)}{Dose\ Rate\ (Gy/ka)} \dots\dots\dots (1)$$

1.3 Mechanism of Electron Trapping and Luminescence: Ionizing radiation drives mineral crystals into a metastable state where electrons are displaced from their parent nuclei. The positions from which the electrons have been evicted act as holes. The electrons and holes then diffuse within the mineral crystals and become trapped separately at lattice defects. Figure 1 shows an energy level diagram that is used to visualize the trapping mechanisms involved in luminescence in crystalline materials. If the crystal lattice is stimulated, by heating to an adequately high temperature or by exposure to an optical source with a suitable wavelength, trapped electrons will be evicted out of the traps. When stimulation is by optical means, OSL will be obtained. Each trapped electron leaves a hole in the valence band, which is soon trapped in a hole trap just above the top of the valence band. A trapped electron (or hole) can be thermally raised to the conduction (valence) band, moving in the crystal and finally recombine with a trapped charge carrier of the opposite sign. The site of possible recombination is called the recombination centre. If the process of recombination results in the emission of light, and take place during the heating of the sample (after the irradiation is ceased) thermoluminescence (TL) is observed. When stimulation is by optical means, OSL will be obtained.

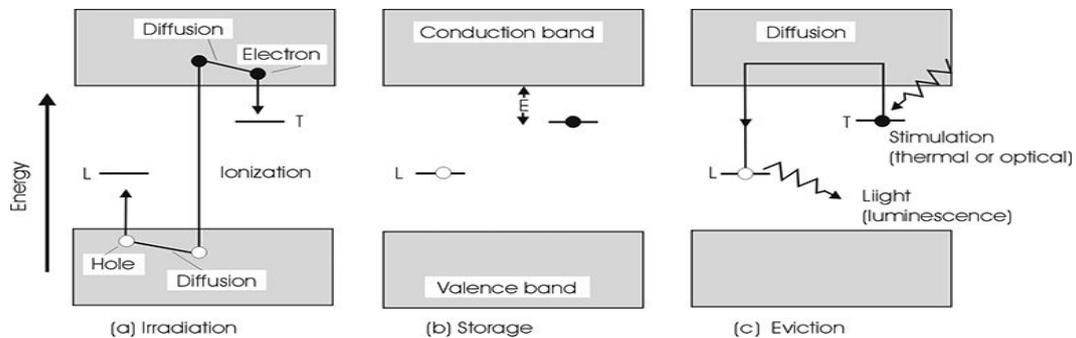


Figure 1: Energy level diagram that shows the creation of luminescence centers in crystal lattices by ionizing radiation [17, 19]. (a) On irradiation, electrons are expelled from their original sites leaving holes behind. (b) At appropriate sites, electrons are trapped while holes may become localized. (c) Thermal (TL) or optical (OSL) stimulation of the material results in electrons being evicted from the traps and light emission on reaching luminescence centers by the evicted electrons.

1.4 TL Glow Curve: The electron eviction temperature is depicted by a peak on a plot of the luminescence signal versus temperature. This peak is referred to as a TL glow-curve. If the heating continues, all the electron traps will be emptied. A glow-curve that is obtained after the first heating of a sample is given in Figure 2. Heating the sample again soon after the first heating will produce a different curve. The second curve corresponds to incandescence that is usually observed when any material is adequately heated to an elevated temperature. Hence, from this second heating, there will be no luminescence from trapped electrons that had accumulated from ionizing radiation since the last zeroing event.

Normally, the shape of the glow curve is one or more peaks, some of which may be overlapped. The shape of the glow curve depends on the light sensitive device (such as photomultiplier tube) and in particular on its spectral response. Also with the same device, the glow curve may look different for different filters inserted between the sample and the detector. All the glow curve characteristics of a given sample, such as the number of peaks, their shapes and their



emission spectral composition, may depend on the nature of excitation. Thus, excitation with UV light may result in a different glow curve than that recorded with other radiations, such as X-rays, α , β or γ -irradiations [19]. Moreover, even with same kind of excitation agents, say UV light, different excitation energies (wavelength), may result in different TL properties. TL glow curves also depend on the dose. Usually, at high dose, the dose dependence curve approaches some saturation value. At low doses, linear dose dependence is quite prevalent; however superlinear dependence as of the lowest doses sometimes occurs. There is dependence upon the dose rate also.

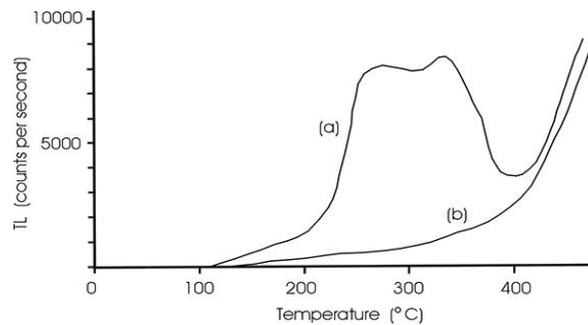


Figure 2. Typical glow-curves obtained on thermal stimulation. (a) A signal yielded after the first heating of a quartz sample with trapped electrons (palaeodose). (b) A glow-curve from incandescence resulting from the second heating of the sample to a high temperature [20].

1.5 Mathematical Models of TL: The first sound theoretical models for the TL phenomena was appeared in 1945. When Randall and Wilkins [21-22] suggested the “First order Kinetics” model while later in 1948 Garlic and Gibson [23] developed another model known as “Second order Kinetics” model. To generalize the models for TL, Halperin and Branner [24] following Adirovitch’s [25] work of phosphorescence proposed a set of three linear differential equation, which described the process of thermal release, re-trapping and recombination of charge carriers. The equations are

$$I(t) = -\frac{dn}{dt} = ns \exp\left(-\frac{E}{KT}\right) \dots\dots\dots (2)$$

$$I(t) = -\frac{dn}{dt} = \left(\frac{n^2}{N}\right) s \exp\left(-\frac{E}{KT}\right) \dots\dots\dots (3)$$

$$I(t) = -\frac{dn}{dt} = n^b s' \exp\left(-\frac{E}{KT}\right) \dots\dots\dots (4)$$

- where,
- E = the activation energy or trap depth (eV);
 - k = Boltzmann’s constant (eV K⁻¹)
 - T= the absolute temperature (K)
 - t = time (s)
 - s = a constant characteristic of the electron trap, called the “pre-exponential frequency factor” or “attempt-to-escape frequency” (s⁻¹). This parameter is proportional to the frequency of the collisions of the electron with the lattice phonons. Typically the maximum values of s correspond to the values of the lattice vibration frequency, i.e. 10¹² - 10¹⁴ s⁻¹.
 - N = the total trap concentration (m⁻³),
 - n = concentration of trapped electrons at time t (m⁻³)
 - b = the kinetic order, a parameter with values typically between 1 and 2
 - s’ = the so-called effective pre-exponential factor for general order kinetics(m^{3(b-1)} s⁻¹).

1.6 Natural Sources of Ionizing Radiation in Relation with TL Dating:

The main natural sources of ionizing radiation that contribute to the trapped energy in geological and archaeological mineral grains include naturally occurring isotopes of uranium (²³⁸U and ²³⁵U) and thorium (²³²Th) decay chains, potassium (⁴⁰K) and rubidium (⁸⁷Rb). These elements are found in natural materials in very low concentrations (about 3–10 parts per million for uranium and thorium and less than 5% for potassium, where ⁴⁰K is one part in 10,000). Despite the low concentrations, these radioactive isotopes collectively emit enough radiation to induce luminescence that is detectable for dating purposes. The radiation emitted includes alpha and beta particles as well as gamma radiation. Cosmic rays also have small contribution to the ionizing radiation. The radiations liberate charge carriers

(electrons and holes) within silicate mineral grains. The charge carriers can subsequently become localized at crystal defects leading to accumulation of a trapped electron population.

II. RELATED WORK

The possibility of dating of unheated sediments by TL was first recognized by Shelkopyas and Morozov [26] in Kiev. In subsequent years extensive work on loess and other sediments was carried out in the Soviet Union [27-30] and China [31]. This dating of sediments has made rapid progress in recent years. TL dating has a major impact on the chronology of human occupation. Readhead [32] was the first to apply TL dating methods to the unheated sediments at Lake Mungo. However, it was several years later when Oyston [33] obtained an age of 43.3 ± 3.8 ka for the sedimentary layer containing human burial remains. He used a new TL procedure [34,35] that involved the selection of the most bleachable part of the quartz TL signal [36]. At Malakunanja, in northern Australia, close to where humans may have first set foot on that continent, an age of 61 ± 10 Ka was obtained for sediments containing the lowest stone artifacts and ochres, and an age of 45 ± 7 ka for sediments overlying a small pit filled with artefacts [37,38]. Luminescence dating has been recently applied to fluvial deposits all over the world [39-42]. In central Europe, Rhine – Mass system was extensively studied, particularly in the upper Rhine Graben and the Lower Rhine area [43,44]. The timing of fluvial aggradations periods is actually of great importance for a better understanding of the fluvial response to climate, tectonic and eustatic variations. Luminescence dating of fluvial sands is also carried out in the basin of the Moselle River, a main left bank tributary of the Rhine [45,46]. The dating results provide a first chronological frame for the youngest fluvial aggradations periods.

III. METHODOLOGY

3.1 Luminescence Dating Reader: Luminescence dating reader aims to determine the amount of energy that has been stored in the mineral grains of a given material since the start of the event that is being investigated. The basic layout of equipment used to measure luminescence in geological and archaeological dating is shown in Figure 3. Modern luminescence dating systems commonly possess both TL and OSL measurement capabilities [47,48]. To conduct a measurement, samples are usually loaded on discs about 1 cm in diameter that sit on an appropriate sample holder in multiples. These are then introduced into the device, commonly referred to as a luminescence reader [49] and selectively moved into position for measurement. The luminescence signal from the sample is captured by a photon detector system like photomultiplier tube (PMT) or charge-coupled device (CCD) camera after passing through optical filters. When conducting TL measurements, the filters exclude infrared signals from the heating but permit blue or violet emissions to pass through. In OSL measurements, wavelengths used for stimulation are rejected by the filters, whereas violet and near ultraviolet wavelengths are usually transmitted. Output from a TL measurement is distinctly different from that obtained using OSL stimulation (Figure 3).

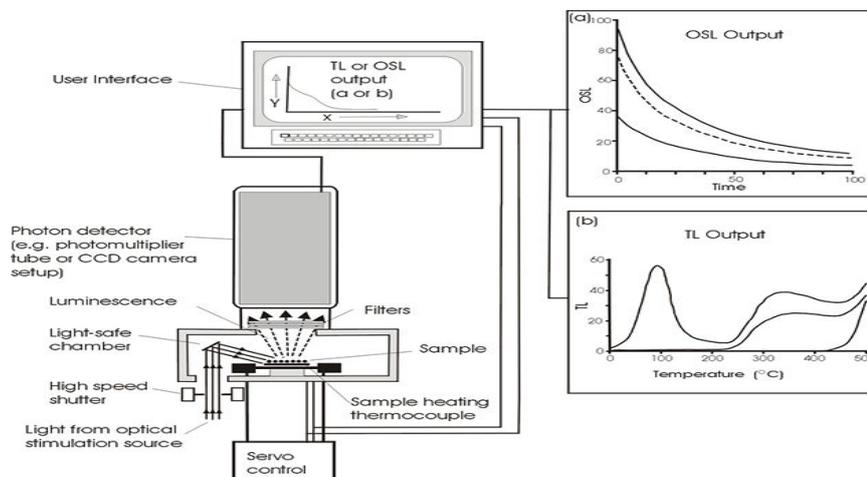


Figure 3. Main components of a luminescence reader that measures both TL and OSL signals [19,20].

3.2 Most Common Luminescence Dating Minerals - Quartz and Feldspar: Although many minerals show luminescence when exposed to ionizing radiation (after stimulation) but all such minerals are not suitable for use in

luminescence dating. In luminescence dating, primarily we use quartz and feldspar. Quartz is the most commonly used mineral in luminescence dating because it offers a number of advantages when contrasted with alternatives. As it is very resistive to both chemical weathering and mechanical abrasion, so it is very stable at the earth's surface. Thus, quartz is one of the most abundant minerals in depositional environments. Quartz's luminescence properties are also very stable. Also, it does not have an internal source of radiation and hence the ionizing radiation that quartz grains receive in nature is usually from an external source, which simplifies dose rate calculation procedures. Quartz with a natural dose shows TL peaks at 325 °C and 375 °C [50]. In TL dating we use the 375 °C peak because it is very stable and is thought to be the result of AlO_4 lattice impurities that serve as hole traps [3]. Under sunlight, the 325 °C peak bleaches much more rapidly than the 375 °C peak [51,52]. Quartz that has been irradiated artificially also shows a peak at 110 °C [Figure 4]. Heating quartz above 300 °C shows a natural TL emission band around 460–480 nm (blue) and another in the region of 610–630 nm (orange). Laboratory irradiated quartz has a TL emission band below 300 °C in the region of 360–420 nm.

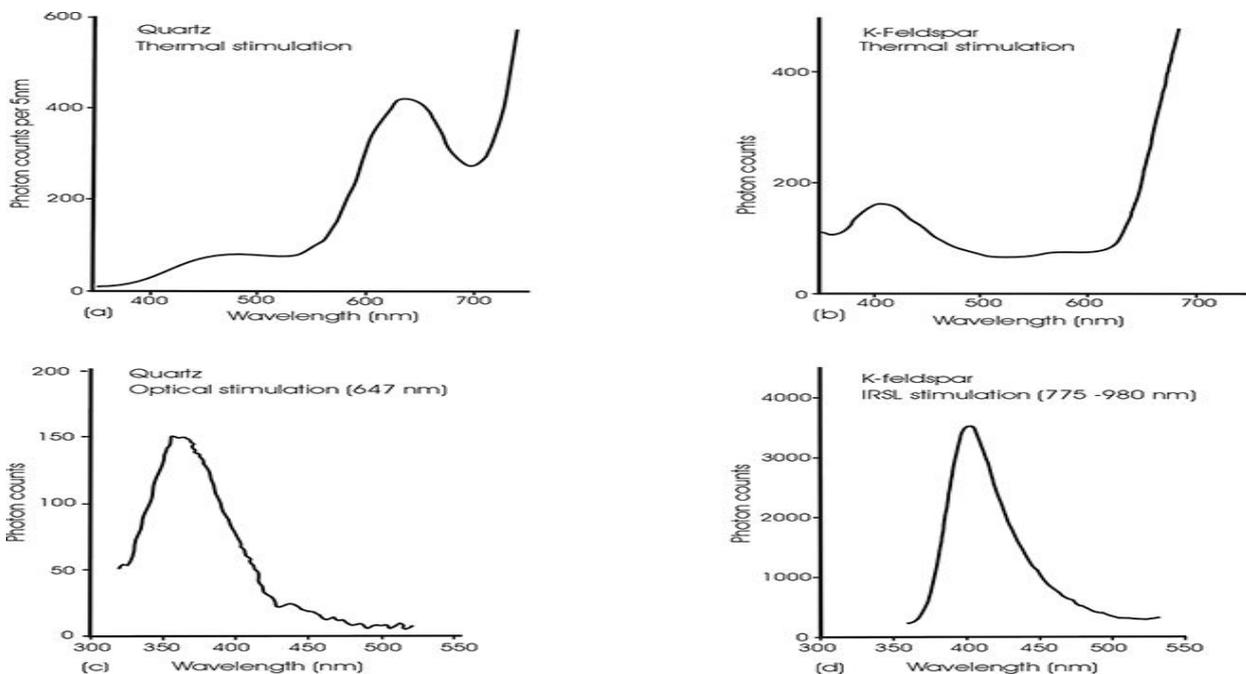


Figure 4: Examples of TL (a, b) and OSL (c, d) emission spectra [51]. For TL spectra, the sharp rise in emissions beyond 650 nm is largely from incandescence (rather than from electrons evicted from traps).

It is reported that quartz shows luminescence when stimulated by wavelengths from any part of the visible spectrum [51]. In case of OSL studies, we prefer use of blue light for stimulation as it yields the higher OSL intensity [48].

Feldspar is a widely used mineral in OSL dating. It constitutes about 60% of the earth's crust. Even though feldspar weathers more rapidly than quartz, it is a very common mineral at the earth's surface. Chemically, feldspars are aluminosilicates that form solid solution series with potassium (K) calcium (Ca) and sodium (Na) as end members of a ternary system. Since potassium has an isotope that contributes ionizing radiation in luminescence dating, the potassium in K-feldspars has to be treated as a source of internal dose, in addition to dose contributions from sources external to the grains. As a result, when dating feldspars, it is necessary to separate K-feldspars from Ca and Na-feldspars.

Compared with quartz, feldspar has a number of attractive luminescence features. (i) Its emissions are generally brighter than those from quartz which produces stronger signals. This means that smaller doses can be measured during analysis. (ii) The internal dose from potassium is not susceptible to external influences such as variations in pore water and this allows dose rates to be ascertained more accurately. (iii) Feldspar can be stimulated using infrared radiation which allows effective separation to be made between the stimulation source and emission wavelengths. But anomalous fading is the main drawback of feldspar [9]. Many researchers reported that K-feldspars extracted from sediments yield

natural TL signals that display peaks at 280°C and 330°C [51]. In terms of emission wavelengths, K-rich feldspars have been reported to show maximums in the range of 390–440 nm (violet to blue) [53]. Wavelengths in the near infrared region (peaking around 880 nm) can also be used to induce luminescence in feldspars. Since this effect was first noticed [54], most research in optical dating of feldspars has focused on infrared stimulated luminescence (IRSL) stimulation. The main advantage of using IRSL is that the rest of the visible spectrum can then be used for emission detection. Nowadays feldspar optical dating use light emitting diodes (LEDs) for stimulation that have emission peaks at around 880 ± 40 nm. LEDs are much cheaper than lasers and are widely available. Sedimentary K-feldspars stimulated using IRSL show a major natural emission peak at 410 nm (Figure 4) and another minor peak in the range of 300–350 nm [55].

3.3 Determination of Palaeodose: To find the luminescence age two parameters are to be determined : the paleodose and the dose rate. The dose refers to the energy absorbed per kilogram of material, and it is measured in gray (Gy), [1 Gy = 1 J/kg]. For materials that were previously zeroed by heating or firing, the start of the accumulation of the paleodose would correspond with the last time the material was heated to a temperature high enough to expel electrons from their traps. In the case of sediments that were zeroed by exposure to sunlight, the start of the accumulation of the paleodose would correspond to the last time that a sample was subjected to the bleaching effects of the sun for a period long enough to evict all trapped electrons. The natural signal refers to the luminescence signal yielded by a sample collected from the field. To determine the paleodose of a sample of unknown age, the natural signal is measured first after which the sample is irradiated artificially using a well-calibrated laboratory-based source. The signals from the artificial dose are then measured and compared with the natural dose signals in order to determine an artificial dose that gives a signal similar to that of the natural dose. This is referred to as the equivalent dose (D_e). Investigators use two main methods to determine D_e : the additive dose and the regenerative dose (or regeneration) methods [56,17].

3.4 Additive Dose Method: In this method, a sample of unknown age is split into two sets of aliquots. The natural signal for one set is measured first after which the second set is irradiated with incremental doses using an artificial source and also measured. The plot of the artificial signals against the dose administered produces a dose–response curve depicting the luminescence signal against the laboratory dose (Figure 5-a). The curve is also known as a growth curve. The natural signal is also plotted on the growth curve against zero dose (Figure 5-a). Extrapolating the curve backwards until it intercepts the horizontal axis at zero signal intensity provides D_e (Figure 5-a) [18]. Growth curves are unique to each sample because luminescence sensitivity of mineral grains can vary from sample to sample. Thus, a new growth curve has to be constructed for each sample whose age is being determined. When dating materials that were zeroed by the sun using TL, the residual TL signal that is noted following solar bleaching would have to be taken into account when extrapolating the curve backwards. With both feldspar and quartz, the relationship between the luminescence signal and the laboratory radiation portrays a linear trend for low and moderate doses. At high doses, the growth curve shows plateaus, indicating that luminescence traps are getting exhausted. This is referred to as saturation.

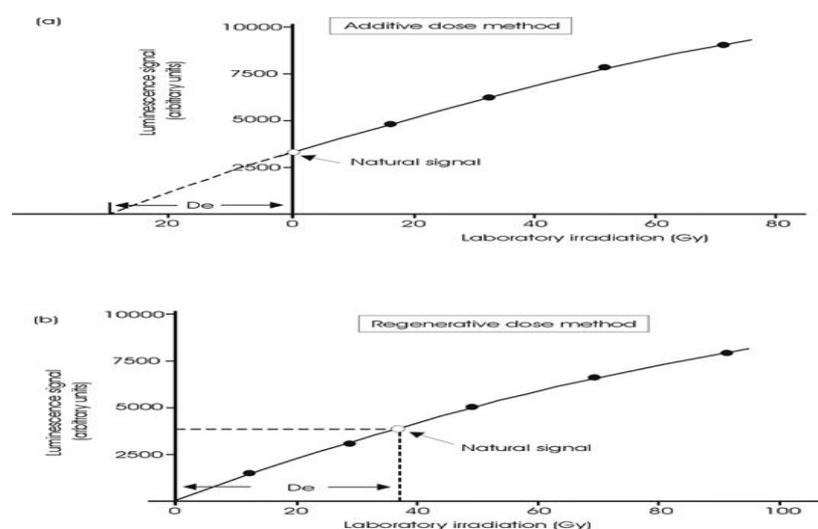


Figure 5. Two main methods employed in determining the equivalent dose. (a) When using the additive dose method, incremental doses are administered on top of the natural dose and then measured. (b) With the regenerative dose approach, samples are first zeroed to remove any previously acquired dose and then given incremental doses, followed by measuring.



3.5 Regenerative Dose Method: Regeneration method also follows a procedure similar to that employed in the additive dose method, but the difference is that before the laboratory dose is applied, the sample aliquots in the regeneration method are first zeroed to remove any previously acquired dose. Incremental doses are then applied to the zeroed aliquots and measured. The acquired signals are plotted against the administered dose to give a regenerative dose growth curve. The signal from the sample of unknown age is interpolated into the growth curve (Figure 5-b) [18]. This gives the equivalent dose. Hence, when constructing the growth curve, the laboratory irradiation doses are selected such that the signals they produce lie above and below the signal obtained from the natural dose.

3.6 Determination of the Dose Rate: As mentioned in the above, ionizing radiation responsible for the energy accumulation in mineral grains in natural settings emanates from uranium and thorium decay chains as well as from potassium and rubidium isotopes. The cosmic radiation also contributes a minor component. To evaluate the total contributions of all these components a number of methods are used. Using the concentration approach, levels of uranium, potassium and rubidium in a given sample are quantified with the help of an analytical procedure such as atomic absorption spectroscopy (AAS), neutron activation analysis (NAA), flame photometric detection (FPD), X-ray fluorescence (XRF) and inductively coupled plasma spectroscopy (ICPS). After the concentrations have been measured, dose rate is determined using special conversion tables prepared for the purpose [17]. For uranium and thorium, there may be isotopic disequilibrium that render the measurements. Thus, these analytical techniques are unreliable for them [17]. Besides the above techniques, direct measurements of the activities of specific radionuclides can be achieved using methods such as alpha or gamma ray spectrometry. These methods can provide accurate measurements, including from uranium and thorium decay chains and in cases where disequilibrium exists. The gamma dose rate is best determined in the field whenever possible. Highly sensitive portable gamma-ray spectrometers that make such onsite measurements possible are now available [49].

Dose rate measurement can also be conducted in the field using synthetic dosimeters such as α - $\text{Al}_2\text{O}_3:\text{C}$ [49]. These are highly sensitive materials that are left in the field for a few weeks after which they are retrieved and analyzed to get the dose rate. The contribution from cosmic rays to the dose is usually little. But, in places where the radionuclide concentrations are low, the proportion from cosmic rays becomes significant and we must consider it. A methodology for calculating cosmic ray contribution to the luminescence dose rate was formulated by Prescott and Hutton [57]. Also, moisture content of the material to be dated should be taken into account when calculating the dose rate. This is because interstitial water absorbs part of the dose. In materials with the large moisture content, the dose rate is attenuated.

In this paper we report the extraction of quartz samples from the sediments of the terraces of Imphal river, Itok river, Thongjaorok river and Thoubal river in the valley of Manipur, India and determination of the age of samples using TL dating technique. We apply the additive dose protocol for determining the equivalent dose of the sample.

IV. EXPERIMENTAL RESULTS

Applications of TL Dating Technique to River Terraces of Manipur

4.1 Experiment(Laboratory procedure)

(a) Extraction of Quartz Samples: Suitable terraces of Imphal river (at Awang Sekmai), Itok river (at Itok), Thongjaorok river (at Bishnupur Chingmang), and Thoubal river (at Leirongthel) of Manipur, India are traced in the field area above modern flood plain. Each terrace consists of nearly 1-4 feet thick gravel capping a strata surface eroded into sandstone bedrock. We have marked and labelled these strata from the lowest to highest. Samples were collected from homogeneous sandy layer in metal pipes under dark room like conditions.

The preparation of samples took place under subdued red light conditions. Sand sized grains of nearly 80-150 μm were extracted from the raw samples by washing with water and sieving. Then, the samples were treated with 30% H_2O_2 and 10% HCl to remove organic and carbonates. Finally they are treated with 40% HF for about 50 minutes to dissolve feldspar grains and to etch the alpha-exposed outer rim of grains. This yields quartz extract for TL measurement.

(b) Measurement: All TL glow curves of the quartz sample of Imphal river, Itok river, Thongjaorok river and Thoubal river were recorded using TL reader, Model 1009I (Nucleonix System Pvt. Ltd. Hyderabad, India) at Luminescence Dosimetry Laboratory, Thoubal College, Thoubal, Manipur. The heating rate used was 5°C s^{-1} with the temperature set from room temperature to 500°C . A second readout was performed to record the background radiation, which includes the black body radiation. The data presented are all with the background subtraction. The samples were γ -irradiated at Life Sciences Department, Manipur University, Canchipur, Imphal, India and Regional Institute of



Medical Sciences (RIMS), Imphal, India. Both natural TL (NTL) as well as N + Yi glow curves were recorded with a pre-heat of the sample upto 175°C to remove bleachable lower temperature glow peaks.

4.2 Results and Discussions

Since the river terraces are important archives that can provide a framework for modelling the fluvial incision as a part of landscape evolution [58] and luminescence dating response to the depositional history, chrono-stratigraphy and climate evolution recorded in the sediments of river terraces so the study of terrace dating is interesting. The natural TL glow curves of the quartz sample of the Imphal river, Itok river, Thongjaorok river and Thoubal river of Manipur, India, along with glow curves of natural (N) + 25 Gy, N + 50 Gy, N + 75 Gy i. e. N + Yi are shown in figures 6(a), 7(a), 8(a), and 9(a) respectively.

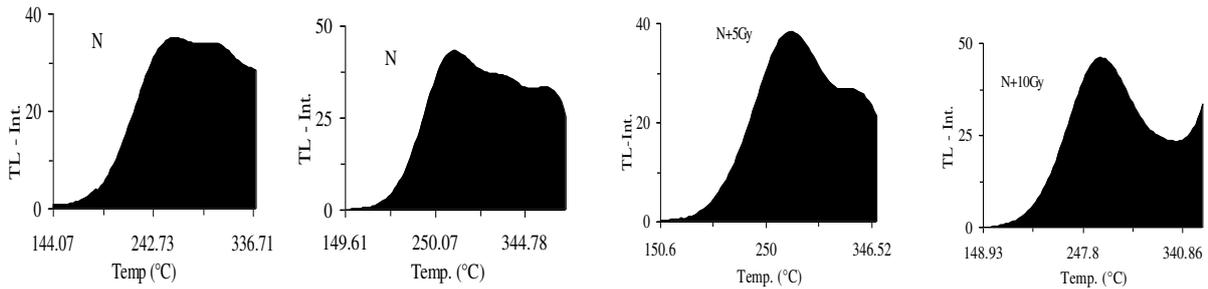


Figure 6(a): Natural TL (NTL) , N+5Gy and N+10Gy γ -irradiated glow curves of quartz extracted from the samples (collected from a depth 10 ft.) of the terrace of Imphal river, Manipur, India.

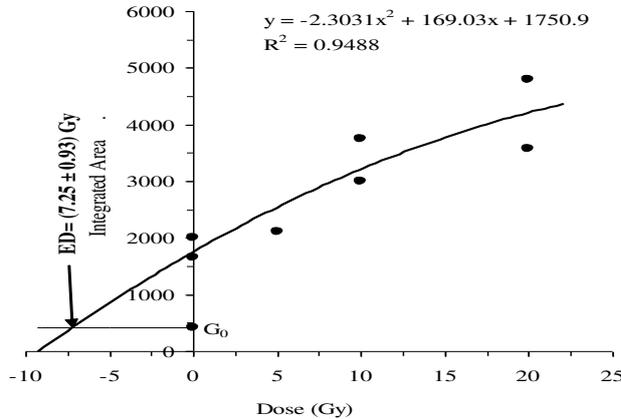


Figure 6(b): Dose Response Curve of the samples of terrace of Imphal river, Manipur, India.

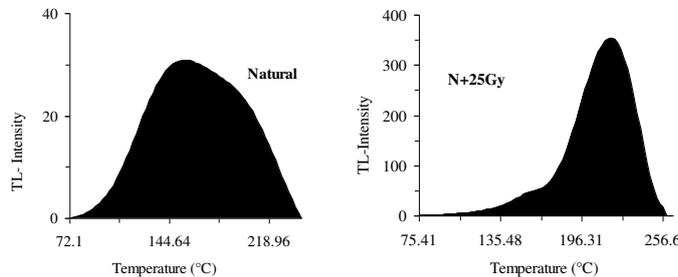


Figure 7(a): Natural TL (NTL), N+25Gy γ -irradiated glow curves of quartz extracted from the sample (collected from a depth a of 10 ft.) of the terrace of Itok river, Thoubal , Manipur, India.

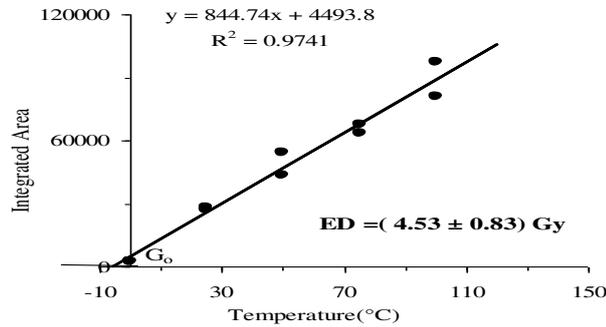


Figure 7(b) : Dose Response Curve of the sample of terrace of Itok river, Thoubal, Manipur, India.

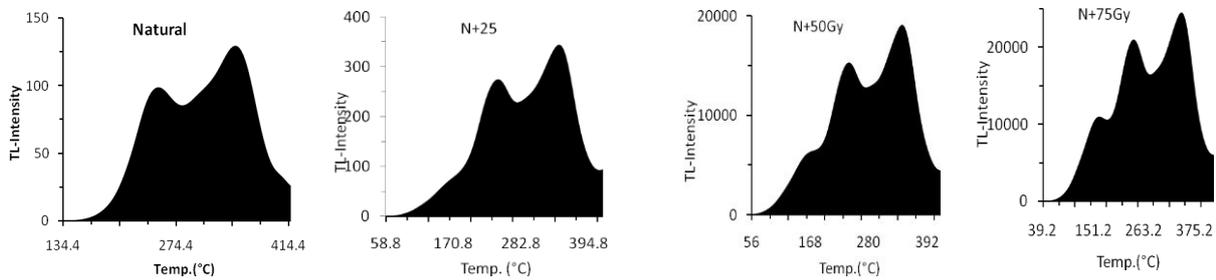


Figure 8(a) : Natural TL (NTL), N+25Gy, N+50Gy and N+75Gy, γ -irradiated glow curves of quartz extracted from the samples (collected from a depth of 15 ft.) of the terrace of Thongjaorok river, Bishnupur, Manipur, India.

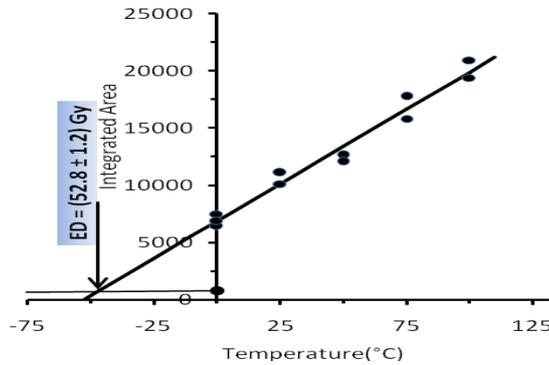


Figure 8(b): Dose Response Curve for the samples collected from the terrace of Thongjaorok river, Bishnupur, Manipur, India.

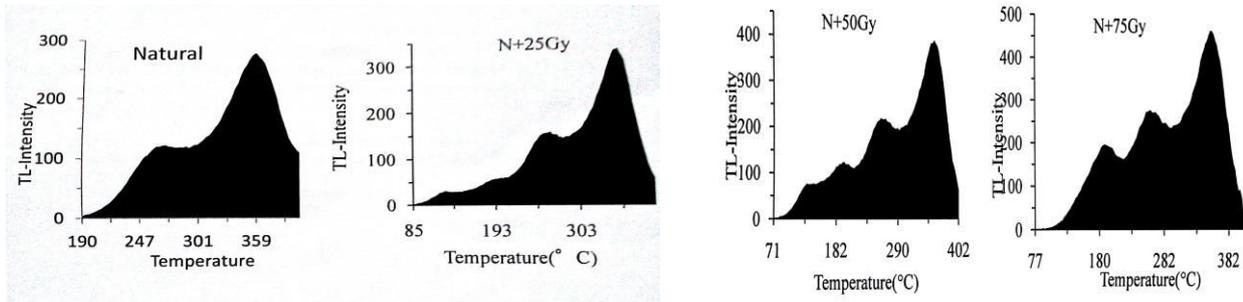


Figure 9(a) : Natural TL(NTL), N+25Gy, N+50Gy, and N+75Gy, γ -irradiated glow curves of quartz extracted from the samples (collected from a depth of 6 ft.) of the terrace of the Thoubal River, Thoubal, Manipur, India.

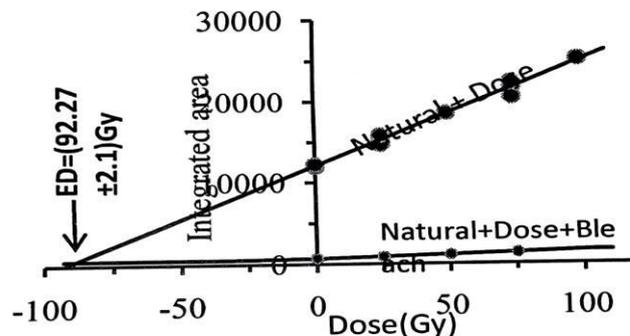


Figure 9(b): Dose Response Curve of the samples collected from the terrace of Thoubal river, Thoubal, Manipur, India. The sample was exposed to sunlight for two days. This causes bleaching of the geological TL of the sample to a residual value G_0 [59]. Figure 6(a), 7(b), 8(b), and 9(b) show the dose response curve (DRC) of the samples collected from Imphal river, Itok river, Thongjaorok river and Thoubal river, Manipur, India, respectively and the respective equivalent dose (ED) is calculated by extrapolation up to the horizontal line through residual value G_0 . Using the dose rate 2.47 Gy/Ka [60] of the region, the age of the samples are determined by using the luminescence age equation (i) and are found to be 2933 ± 400 years, 1190 ± 340 years, $21,380 \pm 480$ years, $37,350 \pm 850$ years of the Imphal river, Itok river, Thongjaorok river and Thoubal river respectively.

V. CONCLUSION

The ages of the sample collected from the terraces of Imphal river, Itok river, Thongjaorok river, and Thoubal river, Manipur, India, determined by TL technique using additive dose method are found to be 2933 ± 400 years, 1190 ± 340 years, $21,380 \pm 480$ years, $37,350 \pm 850$ years of the Imphal river, Itok river, Thongjaorok river and Thoubal river respectively.

The study of the age of sediments of the terrace of these rivers will be helpful in understanding the site formation processes of these sedimentary deposits and in reconstructing the environmental and the climatic change of the river valley of Manipur, India.

Current and Future Directions in Luminescence Dating:

Significant amount of work has been pursued in last few decades in developing luminescence and luminescence dating and exploring its new applications. Achievements have been made in using natural minerals as tool for studying environmental, geological and archaeological sciences.

Further investigation is required to improve knowledge on luminescence characteristics of dosimeters such as feldspar, quartz and others. This should help in more accurate dating and extension of maximum and minimum age limits [61]. More study should be given in developing new technique like surface dating technique using pointed laser beam sources or imaging devices like imaging photon detectors and electron multiplying charge coupled devices [62,63].

For the benefit of mankind, luminescence should be covered the areas like space dating, seismology, volcanic ash dating, loess dating, old cave dating etc.

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