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Dose Determination of Fluvial Sediments in Manisa

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Abstract

Quartz, which is one of the most abundant minerals in nature, can be found in magmatic and metamorphic forms, as well as the usual components of granite and sedimentary formations. Quartz minerals, which are also known as the main component of quartzites, are also known as gangue minerals in many mineralizations. Quartz samples from two different sampling levels, namely the Kaletepe lower and the Kaletepe upper region, used in the study were prepared. Thermoluminescence (TL) glow curves of the samples exposed to radiation with a 90Sr/90Y β source were recorded with a TLD reader. While peaks were obtained at approximately 270 °C from the glow curves of the Kaletepe lower samples irradiated with β source, peaks were obtained at approximately 270 °C and 350 °C from the Kaletepe upper samples. When the annual average dose and age values of the lower and upper Kaletepe samples are examined, it can be said that it was formed in a time period of ~8000 years between two areas with a height difference of 130m.

Keywords: Equivalent Dose, Fluvial Sediments, Thermoluminescence dating, Quartz.

1. Introduction

The increasing importance of radiation research due to technological advancements and the need to determine radiation exposure levels in various fields, including physics and medicine. Luminescence is the emission of light because of the energy absorption of some semiconductor and insulator materials. When a material is exposed to radiation, according to Stoke's law, some of the energy of the incident radiation is absorbed in the material and is released as a longer wavelength light is emitted [1] which describes the relationship between the energy of the absorbed radiation and the wavelength of the emitted light. Luminescence can be used to determine the dose of radiation exposure, as the intensity of the emitted light is proportional to the amount of energy absorbed by the material. Therefore, by measuring the luminescence intensity of a material exposed to radiation, it is possible to determine the amount of radiation to which it was exposed.

The luminescence technique is useful in detecting radiation exposure to humans, using it as a radiation dosimeter, and dating geological artifacts. Some materials having luminescent properties glow when heated after exposure to radiation; this physical phenomenon is called thermoluminescence (TL) [2].

The history of TL research is described, beginning with Robert Boyle's observations in the 17th century on minerals like diamond and feldspar, which exhibit TL properties. The 18th and 19th centuries saw further studies on TL, including the first systematic studies by Wiedemann and Schmidt on materials exposed to cathode rays, and the discovery of the relationship between TL signals and radioactivity, which opened the door to dosimetric studies. The usability of phosphor materials in dose measurement and the TL properties of these materials are among the subjects that have been studied with interest [3]. The band structure of a solid, as well as impurities and lattice irregularities, are factors that affect TL. The wavelength of the emitted photon is a property of the radiating material, rather than the incident radiation [4-6].

Quartz, which is one of the most common minerals in nature, is the usual component of magmatic, metamorphic, especially granite, and sedimentary formations. Quartz minerals, which are also known as the main component of quartzites, are also known as gangue minerals. Many natural materials, such as quartz minerals, have been examined as TL materials, and many materials have been studied in the literature.

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The main components of sediments are quartz and feldspar minerals, and these minerals are constantly exposed to ionizing radiation. The luminescence obtained from quartz is widely used in dosimetry [7, 8] especially in dating geological materials and rocks [9]. Thermoluminescence dose measurements has been used to date various geological materials such as sediments, soils, and archaeological [9].

Thermoluminescence dose measurements of sediments is useful in determining the depositional age and history of sedimentary basins, which can provide important information about the evolution of landscapes and climate [10]. These measurements have also been used to determine the age of archaeological artifacts, such as pottery and burnt stones, providing important insights into the history of human civilization [11].

Quartz grains, which are highly resilient and widely available minerals found on the Earth's surface, have been extensively employed in the process of optically stimulated luminescence (OSL) dating. This dating method is commonly applied to Quaternary sediments spanning various types of depositional environments [11,12]. Recent studies have shown that the luminescence characteristics of quartz can serve as a valuable tool for analyzing the origin and source of sediments. This innovative application of quartz luminescence properties enables researchers to gain insights into sediment provenance, allowing them to determine the geographical origin and transport history of sediments [13, 14].

Thermoluminescence (TL) is also used in archeology and geology to determine the age of sediments and materials. TL dating is based on the principle that some minerals, such as quartz or feldspar, accumulate electrons trapped in their crystal lattice when exposed to ionizing radiation in the medium. Over time, these trapped electrons are released when the mineral is heated, resulting in a measurable thermoluminescence signal. The amount of light released is proportional to the amount of radiation the mineral has been exposed to since the last warming event. They can estimate the age of the sample by measuring the intensity of the emitted light. TL signals from quartz saturate more slowly than signals from other techniques, allowing older sediments to be dated. However, the saturation behavior depends on several factors, such as the specific mineral, the type and intensity of radiation exposure, and the date of burial of the sample. TL dating is typically appropriate for specimens several thousand to several hundred thousand years old. TL dating is often employed for dating older sediments due to the slower saturation of its signal compared to OSL dating. However, the specific age range that can be accurately determined depends on several factors and the limitations of each dating method [15, 16].

In this study, the thermoluminescence (TL) properties of quartz samples obtained from sedimentary formations in the Kaletepe region of the Salihli district of Manisa province were investigated. The quartz samples obtained in the study were prepared from two different elevation levels, namely the lower Kaletepe region and the upper Kaletepe region, with four of each. TL glow curves of the samples exposed to radiation at different times with a $^{90}Sr/^{90}Y$ β source were recorded with the Harshaw 3500 TLD reader - analyzer system. While peaks were obtained at approximately 270 °C from the glow curves of the lower Kaletepe samples irradiated with β source, peaks were obtained at approximately 270 °C and 350 °C from the upper Kaletepe samples. The equivalent dose measurements of the lower and upper Kaletepe region fluvial sediment samples are examined and found as 278.409 ± 13.762 and 182.320 ± 25.293 mGy, respectively. If the ages of the lower and upper Kaletepe region fluvial sediment samples are examined, it can be said that they were formed in a time period of ~8000 years between two areas with a height difference of 130m. The study area is located in the eastern part of the Aegean extensional zone, which is widely known as the active continental expansion zone. For example, there are various studies on the fault system in this field [17, 18, 19, 20]. For this reason, the dose measurement of fluvial sediments in the region is very important in dating previous earthquakes.

2. Material and Method

In this study, it was aimed to investigate the TL properties of sedimentary samples obtained from the Kaletepe area of the Salihli district of Manisa province. Kaletepe locality (Fig.1), which is 10 km away from Salihli district of Manisa province, is located at 38°29' north latitude and 28°01' east longitude.

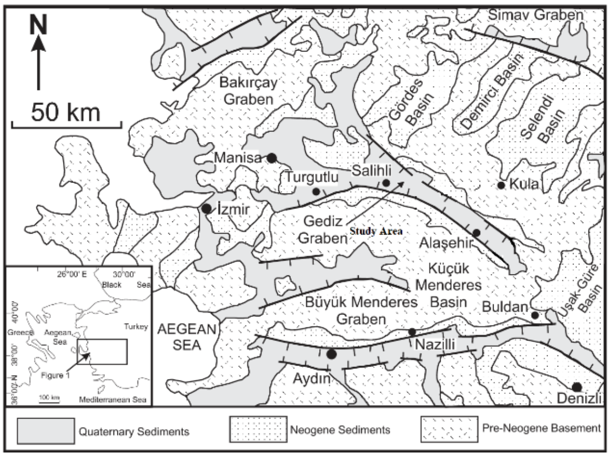

Figure 1. Geological map of the study area showing the Neogene and Quaternary basins of Western Türkiye [17].

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The reason why these samples are preferred is that they are close to the last geological age (the Quaternary) and yield efficient results in radiation techniques and dating. This indicates that the samples that were chosen extremely rich minerals like quartz and feldspar. Sedimentary quartz samples suitable for the study were determined in terms of both mineral contents and luminescence techniques in the field studies carried out in the Kaletepe area of Salihli district. Two separate areas were determined in the sampling area at two different heights, the lower (292nm) and upper (434 m) of the Kaletepe area [17].

When collecting and transporting the samples, care was taken to avoid exposing the sediments to light. As a result of an X-ray diffraction analysis (XRD) of the sediment samples, the quartz minerals were used for dose measurements since the sample contains quartz and is suitable for the system's quartz analysis measurement. The X-ray diffraction analysis (XRD) of sediment samples was performed. As a result of these analyses, the coarse grain method was used to determine the equivalent dose in sediments because the minerals are rich in quartz. Quartz samples with a grain size of 100 µm and above were preferred. Certain chemical procedures have been applied to separate the minerals of the desired grain size from the sediment. In the coarse grain method, sediment samples were first sifted. The samples were then kept in %10 HCl and %30 H_2O_2 solutions, then washed with distilled water until they were completely cleaned. After these processes, the samples were dried in an oven at 60°C. Following these procedures, the samples were washed with distilled water again and checked with a pH meter to see if they had become completely neutral. The neutralized samples were passed through a 140µ sieve with wet sieving and left to dry in the oven again. Quartz was separated from these elements by using a sodium polytungstate ($3Na_2Wo_49WO_3.H_2O$) solution with a density of 2.82 g/cm in order not to encounter any metal in the samples that were subjected to chemical processes. Quartz minerals of the desired coarse grain size were obtained by passing the samples through distilled water again. A single sample of 4–10 mg is sufficient to determine the equivalent dose, but the measurements were repeated with four samples to reduce statistical error. Experimental Studies were carried out at Manisa Celal Bayar University and Ege University Nuclear Sciences Institute.

Four discs of sedimentary samples exposed to radiation at different times with a $^{90}Sr/^{90}Y$ β source were prepared, and TL glow curves of these samples were obtained. Harshaw 3500 TLD reader - analyzer system was used for all TL measurements during the study. This system is a computer-connected hand-operated reader that allows manual reading of TL chips, sticks, and powders in a wide variety of sizes. This reader system is suitable for all applications that require TLD detectors. The Harshaw TLD Model 3500 reader-analyzer system includes a sample drawer for the single-element TL detector, a linear, programmable heating system, and a cooled photomultiplier tube with associated electronics for measuring TL light output. Planchet heating includes a welded thermocouple for the best temperature repeatability. Operating software, WinREMS, running on a separate computer, provides the user interface, reader control, and application software. With this system, samples can be heated up to 600 °C. Owing to the PM tube, the incoming signals are amplified, and the data is processed and recorded by the computer to which the WinREMS program is connected.

3. Results and Discussion

In this study, the luminescence curves of the samples obtained from the lower and upper Kaletepe areas were irradiated at different times using the $^{90}Sr/^{90}Y$ β source with a half-life of 28 years and an activity of 650 MBq and having dose rate 5.30±0.60 mGy/s were recorded with a TLD reader.

In the study, after measuring the natural signal of the samples, the glow curves were recorded by applying preheat temperatures of 230, 240, 250, and 260 °C for the lower Kaletepe region (Fig. 2) and 220, 230, 240, and 250 °C for the upper Kaletepe region (Fig. 2), respectively. After the preheating temperature was determined, the dose response curve of the sample was determined. When the glow curves obtained are examined, it is seen that they were obtained with preheating of 250 °C for the Kaletepe lower sample and 230 °C for the Kaletepe upper sample. Therefore, at the stage of determining the equivalent dose, it was decided to apply these determined preheats to the TL measurements.

First, the natural signal of the prepared samples was taken, and then the doses of 19, 57, 114, and 280 Gy were given to the samples of the $Sr\text{-}^{90}ß$ source and the Kaletepe lower region, and doses of 19, 57, 114, 153, and 280 Gy to the samples of the Kaletepe upper region (Fig. 3). After each irradiation, glow curves from 50 °C to 450 °C and background measurements were obtained with a Harshaw TLD reader at a heating rate of 2°C.s^{-1}. Using these measurements, clear glow curves were recorded.
When TL luminescence curves of the Kaletepe upper quartz sample were examined, TL luminescence signals were observed at approximately 270 °C and 370 °C (Fig. 3.). As a result of the exposure of the Kaletepe upper quartz sample to the beta source for a long time, it was observed that the TL intensity increased with increasing dose (Fig. 3).

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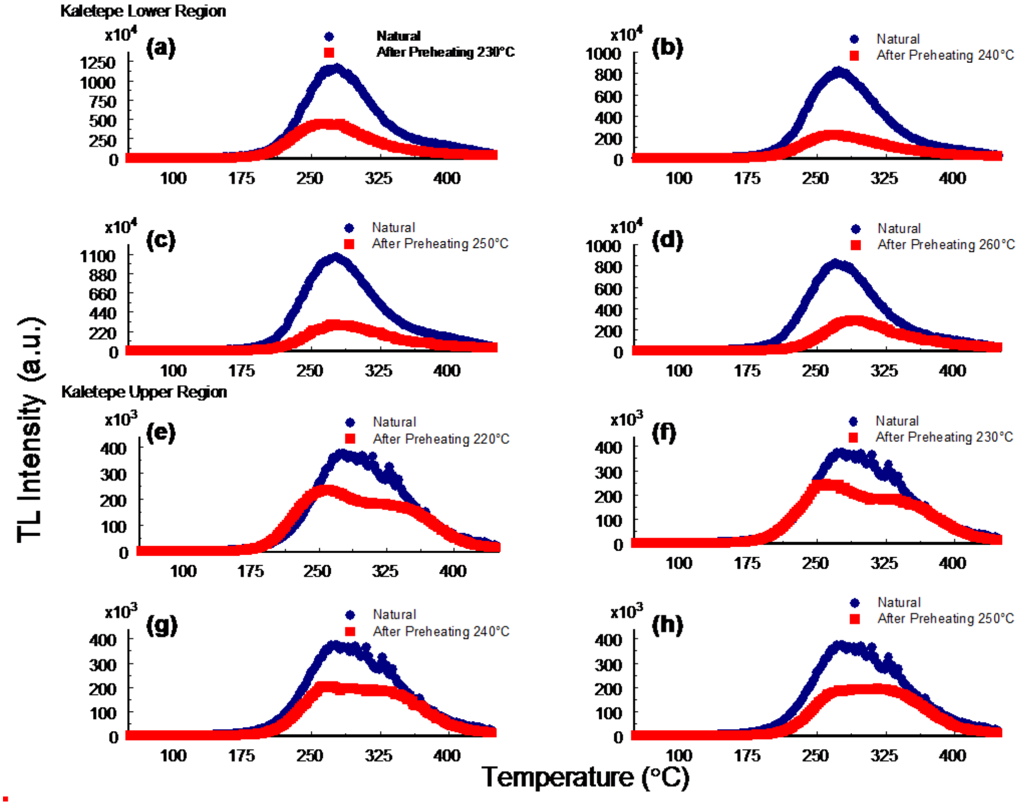

Figure 2. Glow curves of Kaletepe lower and upper region samples obtained because of natural and preheating at (a) 230 °C, (b) 240 °C, (c) 250 °C, (d) 260 °C, (e) 220 °C, (f) 230 °C, (g) 240 °C and (h) 250 °C respectively.

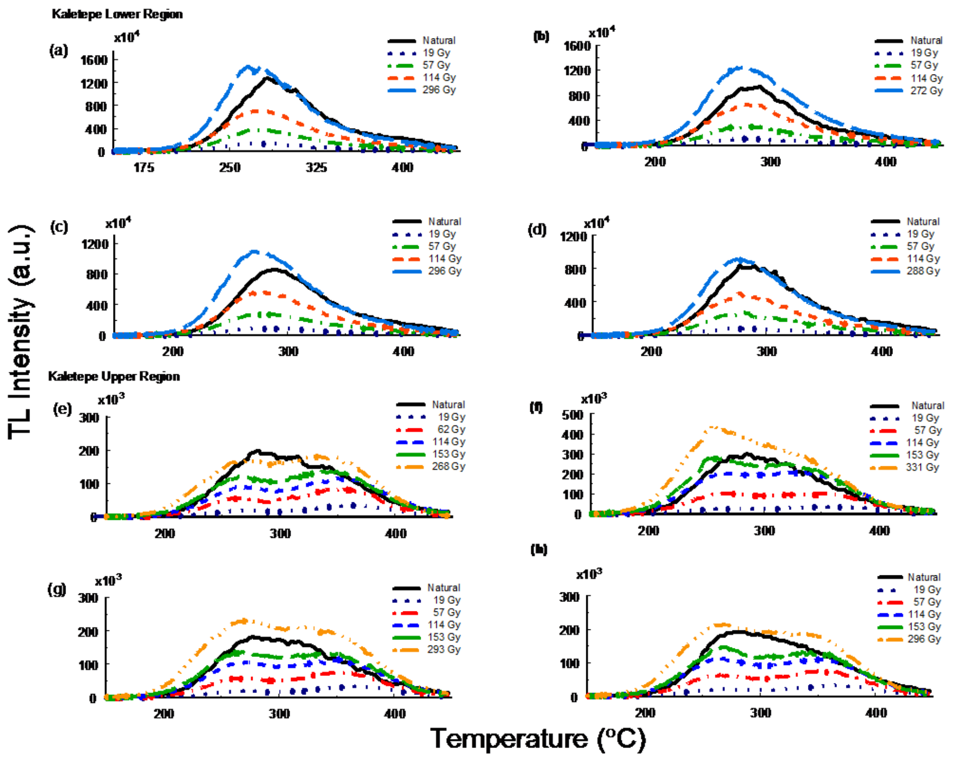

Figure 3. TL glow curves of the Kaletepe lower and upper region quartz sample after irradiation at different doses with Sr-^{90}ß source and natural dose.

Peaks were obtained at approximately 270°C from the glow curves of the Kaletepe lower samples irradiated with a dose of 296 Gy. It can be said that the TL intensity of the samples exposed to the $^{90}Sr/^{90}Y$ beta source for a longer time is higher. As can be seen from the TL glow curves of sediment samples obtained from two different altitudes, Kaletepe lower and Kaletepe upper, the samples taken were found to be suitable for thermoluminescence studies. When planning such studies, supplying materials from different locations of the sedimentary areas will be very productive for the study. In addition, with the results of these studies, studies related to the age determination of sedimental samples in this region were carried out, and useful results were obtained [21]. From the ratio of the glow curves to each other, it was observed that there was a plateau between 300 and 316 °C for the lower samples of Kaletepe (Fig. 4) and between 250 and 265 °C for the upper samples of Kaletepe (Fig. 4).

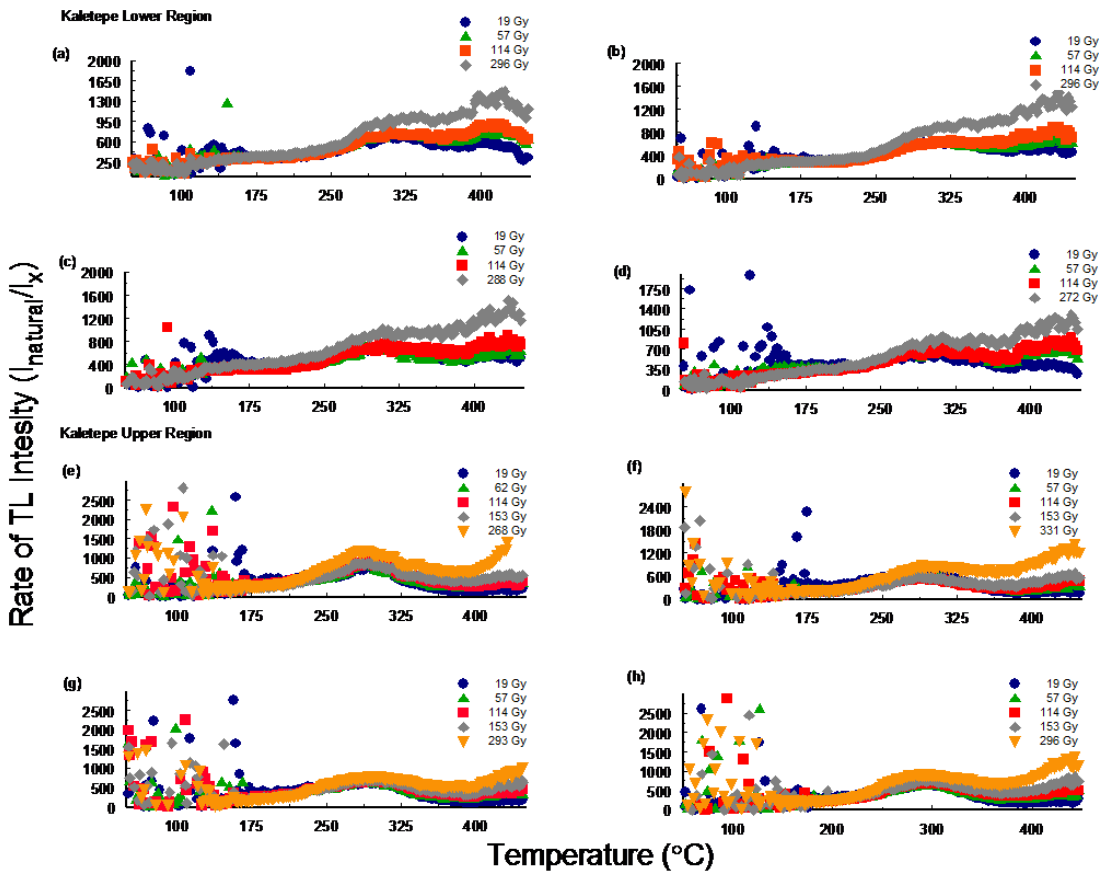

Figure 4. Plateau test results of Kaletepe lower and upper region samples ($I_{natural}$: Natural signal intensity, I_x: x dose-related intensity).

Growth curves were drawn for both areas using the integrations in this temperature range. The dose value corresponding to the natural signal on these curves gives the equivalent dose of the samples. The ages of the samples were determined from the ratio of the equivalent dose values to the annual dose values calculated for the selected areas. The annual dose rates of the samples were taken as stated in the study [21].

The line equation obtained from the growth curves was used to determine the point where the natural signal intersects the x-axis. Equivalent dose values were calculated from these quartz samples. According to these results, the Kaletepe lower sample equivalent dose was calculated 278 ± 14 Gy (Fig. 5), and the Kaletepe upper sample was calculated 182 ± 25 Gy (Fig. 6).

By determining the annual dose rate and equivalent dose values in both areas, the date on which the quartz particles obtained chemically from the sediment samples transported by the river saw the last light was determined. Considering the average annual dose values, the age of the sediment sample belonging to the lower area of Kaletepe was 91.282 ± 24.649 and the age of the sediment sample belonging to the upper area of Kaletepe was calculated as 83.062 ± 28.253 (Table 1).

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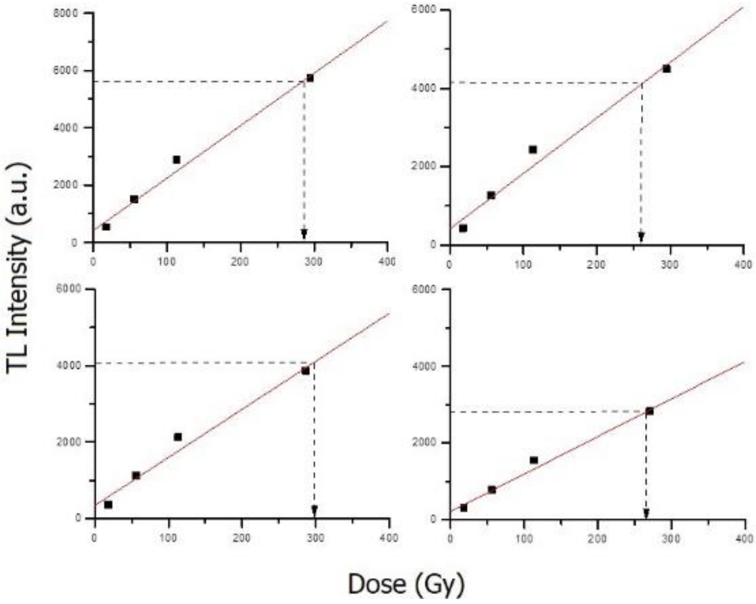

Figure 5. Growth curves of Kaletepe lower samples.

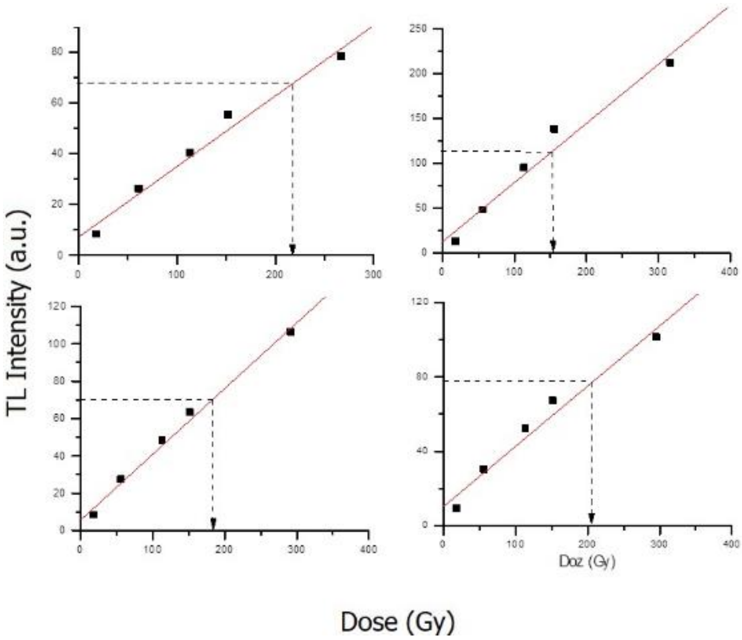

Figure 6. Growth curves of Kaletepe upper samples.

Table 1. The equivalent dose calculated for the lower and upper Kaletepe samples, the annual dose and age values [21].

Age =[Equivalent Dose (mGy)] / [Annual Dose (mGy/y)]

	Kaletepe (lower)	**Kaletepe (upper)**
Equivalent Dose (mGy)	278.409±13.762	182.320±25.293
Annual Dose (mGy.y^{-1})	3.05±0.82	2.20±0.69
Age (y)	91.282±24.649	83.062±28.253

According to the annual mean dose values, the age of the Kaletepe lower area was calculated 91,282 ± 24.649 years and the age of the Kaletepe upper area was calculated 83.062 ± 28.253 years. Considering the average annual dose and age values obtained, it can be said that it was formed in a time period of ~8000 years between the upper and lower areas of Kaletepe with a height difference of ~130 m. According to these results, it can be thought that the events that enabled the transport of fluvial sediments occurred in the Salihli - Kaletepe region of Manisa Province about 90 thousand years ago [22].

4. Conclusion

In this study, Salihli-Kaletepe region fluvial sediment samples were dated by thermoluminescence (TL) techniques. A coarse-grained technique was used for dating studies. Annual dose rate and equivalent dose values for both regions (lower and upper Kaletepe) were determined from sediment samples carried by the river. Thus, the ages of the fluvial sediments obtained by chemical means were determined.

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Data availability

The graphs created with the data obtained during the study are presented. Data generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author's Contributions

Müjde Durukan Gültepe: Designed the research and created the article and then critically reviewed the article and unanimously approved the final draft.
Arzu Ege: Collected samples from the Kaletepe location in accordance with the processes and took measurements after chemically processing them and making them suitable. Guided and supervised the whole process.
M. Durukan Gültepe, A. Ege revised the manuscript; and all authors read and approved the fnal manuscript.

Ethics Declarations

There are no ethical issues after the publication of this manuscript.

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