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LUMINESCENCE AGES OF FELDSPAR CONTAMINATED QUARTZ FROM FLUVIAL TERRACE SEDIMENTS

NAFIYE GUNEC KIYAK[1] and M. KORHAN ERTURAÇ[2]
[1]*ISIK University, Faculty of Science and Arts, Physics Department, Sile, 34980 Istanbul, Turkey*
[2]*Istanbul Technical University, Eurasia Institute of Earth Sciences, Maslak, 34398 Istanbul, Turkey*

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Abstract: This study focuses on obtaining luminescence ages in feldspar contaminated quartz from well-developed fluvial terraces of the Yesilirmak (Iris) river located inside the eastern North Anatolian Fault Shear Zone (NAFZ). We applied a technique based on conventional single-aliquot regenerative-dose (SAR) protocol, modified with an IR pre-treatment to reduce the OSL contribution from feldspar for accurately measuring the dose in quartz. All investigated samples showed an ability to measure a beta dose given in the laboratory, a so called dose recovery test. The dependence of the equivalent dose on thermal treatment was also examined. Dose rate calculations were based on spectral analysis of gamma measurements by a field spectrometer on site. The efforts to establish a chronology using the IR modified SAR technique produced reliable dose results in stratigraphic order. Results were reproducible and grouped broadly between 35-109 ka for Bektemur, 32-36 ka for Kizilca, 19-47 ka for Aksalur and 35-44 ka for Sahinkaya. Obtained results show that the studied area was controlled by tectonic activities within the last 50 ka and the sample Aksalur 2 was the loess deposit formed by aeolian activity.

Keywords: OSL dating, feldspar, quartz, terrace sediments, SAR dose protocol.

1. INTRODUCTION

The single aliquot regenerative dose (SAR) protocol (Murray and Wintle, 2000), as a sequence of measurements, uses the initial part of the OSL signal from quartz or feldspar grains in dating studies. Quartz grains are normally extracted from sediment material using conventional chemical separation methods. However, in some cases – as presented in this study – the grains cannot be separated properly after employing usual chemical treatments and can be contaminated with feldspar (Fragoulis and Readhead, 1991). In case of feldspar contamination, feldspar grains have the OSL signal much brighter than the signal from quartz, resulting in incorrect equivalent dose due to anomalous fading (Huntley and Lamothe, 2001; Wallinga *et al*., 2001). In a previous study, Duller and Bøtter-Jensen (1993) suggested the use of the blue-stimulated luminescence signal following an exposure to infrared (IR) light at room temperature to reduce the blue-stimulated signal from coarse-grained feldspars. The following years the infrared (IR) treatment before blue-stimulated OSL measurement was also used by various authors to obtain a quartz-dominated OSL signal from polymineral geological samples (Banerjee *et al*., 2001; Roberts and Wintle, 2001). Jain and Singhvi (2001) investigated the effect of IR at elevated temperatures on the OSL signal and Wallinga *et al*. (2002) suggested a technique based on the single aliquot regenerative dose (SAR) protocol (Murray and Wintle, 2000), that allows measurement of the dose in quartz in the presence of feldspar contamination.

In the present study, we first examined the applicability of the new SAR technique, suggested by Wallinga *et al*. (2002), in the dating of feldspar contaminated quartz from fluvial terrace sediments collected from the eastern part of North Anatolian Fault Shear Zone (NAFZ) system. Secondly, the influence of preheat temperature, and IR exposure temperature and time on OSL signal intensity was examined. Finally, OSL ages were presented for

Corresponding author: N. Gunec Kiyak
e-mail: kiyak@isikun.edu.tr

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the samples that help to define the history of terrace formation and tectonic activities.

2. SAMPLING

Sampling site

The sampling area is located in the eastern North Anatolian Fault Shear Zone (NAFZ), which is the one of the most active continental strike-slip tectonic zones of the world (**Fig. 1**). The studied terraces are fluvial and formed at various elevations on the gorges of the two major branches of Yesilirmak (Iris) river, joining inside of a young pull-apart basin. They are geomorphic surfaces that have been exposed by tectonic uplift.

The western terrace Bektemur (elevation of 441-461 m) was sampled at one well-exposed section consisting of coarse grained bed load deposits with sand bars very close to the recent course of Cekerek river meandering at 435 m. Three samples (Lab code BKT01, BKT02, BKT03) were collected between 452 and 459 m. The eastern terrace system of Yesilirmak is much more complex as terraces are exposed at various elevations. These terraces are classified into three groups (Kizilca, Aksalur and Sahinkaya) and correlated using their sedimentological properties and elevations. The Kizilca terrace (420- 430 m) was sampled at two cross bedded sand bars inside coarse grained bed load deposits between 417 and 418 m (Lab code KZC01, KZC02). Aksalur (428-450 m) was sampled at a sand bar within bed load deposits (Lab code AKS01, AKS02) between 435 and 449 m, where AKS02 was from a 2 m thick loess layer overlying the terrace sediments. Sahinkaya further divided into Sahinkaya-I (457 m) and Sahinkaya-II (438 m). They consist of thinly bedded silty sand layers of former flood plain deposits and two samples were collected from terraces Sahinkaya-1 and Sahinkaya-2 (Lab code SHK01, SHK02). All samples were collected at night under dim red light conditions, to protect the sediment material from daylight.

Sample preparation and instrumentation

The grains were separated in the size range between 90 and 180 µm using wet sieving and then treated first with 10% HCl to remove carbonates following 20% H_2O_2 treatment for the removal of organic matter. After etching the samples by HF, quartz grains were separated from feldspar using a sodium polytungstate solution prior to HCl and distilled water treatments. The purity of quartz was tested by monitoring the presence of feldspar through measuring the IRSL and a feldspar originated signal was observed in all samples.

OSL measurements were made with an automated Risø TL/OSL DA-15 reader, using an internal $^{90}Sr/^{90}Y$ beta source (~0.1 Gy s^{-1}). The mineral grains were mounted on 10 mm diameter discs with Silkospray silicone for OSL measurements. The luminescence signal was detected through U-340 filters. Blue light emitting diodes (LEDs) (470 nm, ~40 mW cm^{-2}) and IR LEDs (875 nm, ~135 mW cm^{-2}) were used for stimulations (Bøtter-Jensen *et al.*, 1999a and Bøtter-Jensen *et al.*, 1999b).

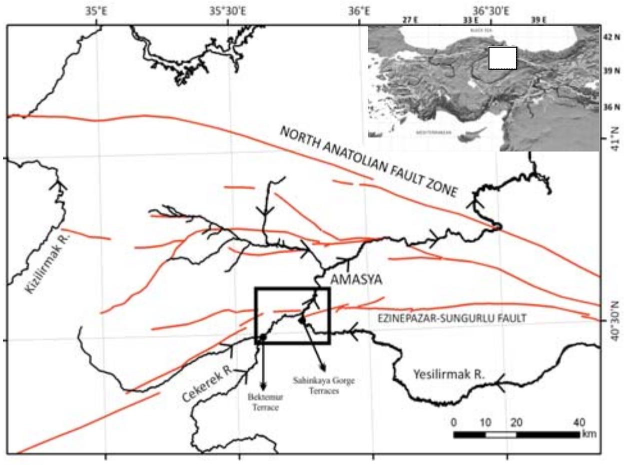

Fig. 1. *The study area is located in the eastern North Anatolian Fault Shear Zone (NAFZ), one of the most active continental strike-slip tectonic zones of the world.*

Dose rate measurements were performed using a field gamma spectrometer recording the gamma spectra for about 7200 s at each sample location. The gamma spectrometer used in the study (model Target-IdentiFINDER) is a complete digital gamma spectroscopy with standard detector NaI(Tl) and dose rate system, integrating multichannel analyzer and memory with an integral scintillation detector. The system has the ability to store 50 spectra of 1024 channels that can be directly transferred to any PC for further analysis. Field gamma dose rate and gamma spectra were directly measured on site. Radionuclide concentrations of decay isotopes of U and Th series, and potassium were calculated using separable peaks of the spectra recorded in situ and then contributions of decay isotopes and potassium to beta dose rate was obtained using gamma dose rate and conversion factors (Olley *et al*., 1996). The altitude, latitude, longitude and depth of samples below the present surface were used to estimate the cosmic ray component of the dose rate as presented by Prescott and Hutton (1994; 1988).

3. SIGNAL CHARACTERISTICS

The effects of preheat and stimulation temperatures on IR bleaching

The effect of IR stimulation temperature on the fast component from quartz has been studied by several authors (Duller, 1994; Strickertsson, *et al*, 2001). They reported that the contribution of feldspar to the fast component of the blue-stimulated OSL signal can be removed by IR treatment at low stimulation temperatures. Some authors also reported that the use of the IR stimulation at elevated temperatures removes the contribution from slower components to the initial part of OSL signal (Jain and Singhvi, 2001 and Wallinga *et al*. 2001). They showed that a 100 s exposure to IR at 175°C made the smallest contribution of feldspar to the OSL signal. LM-OSL measurements at elevated temperatures indicate that the fast component from quartz is hardly affected by IR stimulation temperatures up to 125°C, whereas for higher temperatures during IR exposure the OSL signal decays significantly (Bulur, 1996). These results are similar to those reported by others (Wallinga *et al*., 2001; Bailey, 1998; Banerjee *et al*., 2001). We obtained similar results in our experiments as shown in **Fig. 2**. The effects of preheating and stimulation temperature on feldspar contaminated quartz grains were examined for a representative sample BKT02. Experimental procedures are outlined in the figure captions in which the effects of preheating and IR bleaching at different temperatures are presented. Based on these observations we applied the measurement sequence for the dose determination suggested by Wallinga *et al*. (2002) as presented in **Table 1**.

Equivalent dose D_e and growth curves

Equivalent doses were measured for the studied samples using the SAR sequence added IR bleach prior to each OSL measurement (**Table 1**). In the sequence of measurements a 10s preheat at 260°C was applied to the aliquots followed by the infrared (IR) bleaching for 100 s at 175°C to reduce the magnitude of the OSL signal from feldspar. Then natural and irradiated aliquots were measured by OSL for 40 s at 110°C (L_n, natural dose signal; L_i regenerative dose signal). A test dose (10-20% of natural dose) was given to the aliquots to monitor the sensitivity change between cycles (T_n, natural test-dose signal; T_i regeneration test-dose signal). The observed L_n, L_i, T_n and T_i were derived from the initial OSL signal minus a background estimated from the last part of the stimulation curve.

The sensitivity-corrected growth curve was derived from regenerative dose points (L_i/T_i) plotted against laboratory dose D_i. Growth curves for representative samples from each sampling site are shown in **Fig. 3** and each curve can be approximated with a single exponential function. The equivalent dose D_e for each sample was obtained from the interpolation of the corrected OSL measurements (L_n/T_n).

The equivalent doses, D_e, are presented in **Table 2**; corresponding recycling ratio (corrected signal ratios of repeated dose measurements) and recuperation values (the signal observed for zero dose) are shown in **Fig. 4**. The average D_e values obtained agree well with stratigraphy. There is no significant deviation of the recycling ratios from unity, suggesting that the sensitivity correction is successful and recuperation values are also satisfactory as internal check of reliability of measurements.

Dose recovery tests and preheat plateau

A "dose recovery" test was applied to unseparated bleached quartz and feldspar grains for all investigated samples using various preheat treatments between 220 to 280°C to check the temperature dependence of D_e. The sequence of measurements was identical to those described for natural dose determination in **Table 1**. A laboratory dose of 60 Gy was given to bleached aliquots and then the aliquots were grouped in three, each group was preheated at different temperatures from 220 to 280°C prior to IR treatment. The ratio of a given to a measured one obtained at various preheat temperatures from mixtures of the minerals (from laboratory irradiation) are presented in **Fig. 5**. Disregarding the sample SHK02, the ratios of given dose to measured dose averaged for all investigated samples were within 10% of unity at a preheat temperature of 260°C. In **Fig. 6** the results of D_e are shown for all samples measuring at 260°C preheat treatment, indicating a good recovery of 60.0 Gy laboratory dose. Recycling ratios for each ther-

Table 1. *The SAR-protocol recommended for feldspar contaminated quartz samples by Wallinga et al. (2002) and used in this study.*

Step	Treatment	Observed signal
1	Give dose, D_i	
2	Preheat, 260ºC for 10s	
3	Stimulate with IR, 175ºC for 100 s	
4	Stimulate with blue light, 40 s at 110ºC	L_n, L_i
5	Give test dose, D_t	
6	Heat to 180ºC	
7	Stimulate with IR, 175ºC for 100 s	
8	Stimulate with blue light, 40 s at 110ºC	T_n, T_i
9	Repeat 1 to 8 for D_i	

L_n, L_i and T_n, T_i are derived from the OSL curve, taking the first 0.8 seconds of the initial OSL signal, minus a background estimated from the last 4.0 seconds of the OSL signal.

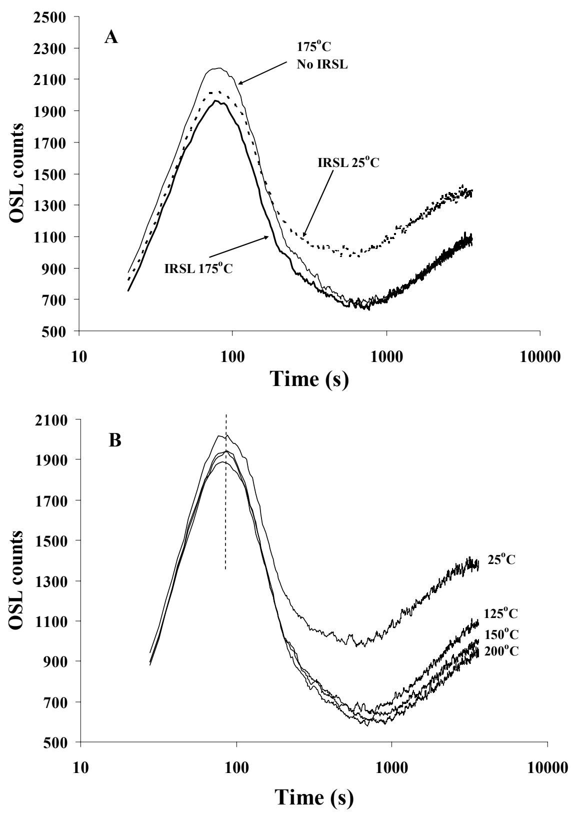

Fig. 2. *LM-OSL curves from mineralogically unseparated grains of sample BKT02. A – LM-OSL curves measured following IR bleach at 25°C (hatched) and at 175°C (thick line) for 100 s. A third LM-OSL curve measured without IR bleach following a preheat temperature of 175°C (thin line) is also shown. B – LM-OSL curves measured using IR bleach at elevated temperatures between 25-200°C. Peak position of the initial signal does not change with IR treatment at elevated temperatures.*

Table 2. *Information about the samples used in this study; SAR dose in Gy, the total dose rates in Gy/ka and ages in ka, are presented.*

Sample code	Type	Location	Depth (cm)	Age (ka)	Equivalent dose D_e (Gy)	Dose rate* (Gy/ka)	n**
AKS01	Eolian	Aksalur	200	18.5±2.7	38.5±5.6	2.09±0.02	14
AKS02	Fluvial	Aksalur	1500	47.0±2.2	93.4±4.2	1.99±0.02	16
BKT01	Fluvial	Bektemur	200	34.7±2.5	44.2±3.1	1.27±0.02	14
BKT02	Fluvial	Bektemur	700	97.9±7.1	119.9±4.4	1.11±0.02	18
BKT03	Fluvial	Bektemur	900	109.5±7.4	129.7±8.5	1.19±0.02	13
KZC01	Fluvial	Kizilca	200	32.1±4.4	69.3±9.4	2.16±0.02	14
KZC02	Fluvial	Kizilca	300	36.9±1.6	78.8±3.1	2.13±0.02	10
SHK01	Fluvial	Sahinkaya	200	35.2±6.9	76±15	2.15±0.02	14
SHK02	Fluvial	Sahinkaya	300	43.4±4.4	91.3±09.1	2.10±0.02	12

*Based on gamma spectrometry separable peak results, converted to dose rates using data of Olley *et al.* (1996), and cosmic ray contribution based on Prescott and Hutton (1994; 1988)

**The number of aliquots. Standard errors in equivalent dose were calculated using the results from “n” aliquots.

mal treatment were close to unity; this indicates that the test-dose sensitivity correction proposed in the modified SAR procedure works well.

4. LUMINESCENCE AGES AND DISCUSSION

The results are summarized in **Table 2**, where OSL-SAR doses are presented in Gy, the total dose rate in Gy/ka and ages in ka. The depositional ages of the terraces are 34-109 ka for Bektemur; 18-47 ka for Aksalur; 32-36 ka for Kizilca and 35-43 ka for Sahinkaya (**Fig. 7**). The OSL ages between 34-109 ka for Bektemur terraces are well consistent with stratigraphy and the dose rate in this area is relatively low, between 1.11 and 1.27 Gy/ka. The Bektemur terrace is the oldest fluvial deposit dated in this study and not very higher than average elevation of the recent flood plain of the Cekerek River (~25-30 m). This age data suggest that western end of this tectonic basin is no longer active. The trenching of these former deposits is probably due to the easterly lateral drift of Cekerek River triggered by rapid subsidence at the eastern margin of the basin. The observed oblique faults cutting the layers of sediments at Bektemur site indicate that this area was subjected to tectonic deformation before ~30 ka, at least.

The terraces Aksalur, Kizilca and Sahinkaya are located on the southern block of an active strike-slip fault system named Ezinepazar-Sungurlu fault (Şengor *et al.*, 2005) which is observed as a wide shear zone with P shears with reverse component and R shears with normal component (**Fig. 1**). The geometry of these faults causes the southern block to uplift, forming a young pull-apart basin. Nevertheless, it is important to examine the field evidence for the presence of minor faults between the sites in order to find a reasonable explanation of the terraces (Aksalur and Sahinkaya 1 and 2) to be formed in the same period of time and exposing at similar elevations. It is clear from our ages that this region faced an intense tectonic activity within the last 50 ka. The precise displacement and average uplift rate in this area will be

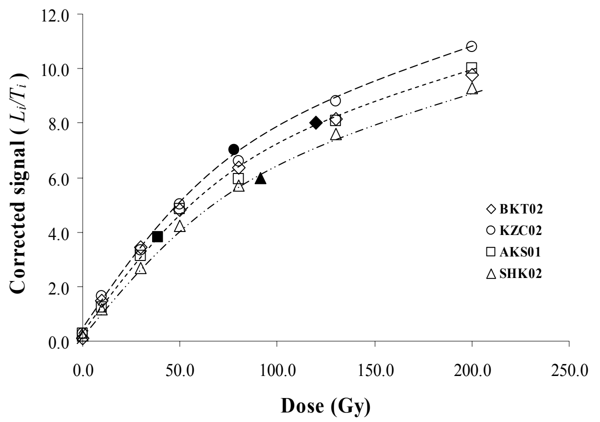

Fig. 3. *Growth curves for representative aliquots from each sampling site. Regenerative doses were from 0 to 200 Gy and the test dose was 6 Gy. The growth curves are similar to each other and each can be described by an exponential function. The growth curves of two samples (AKS01 and BKT02) are overlapped. Filled symbols indicate the natural dose points.*

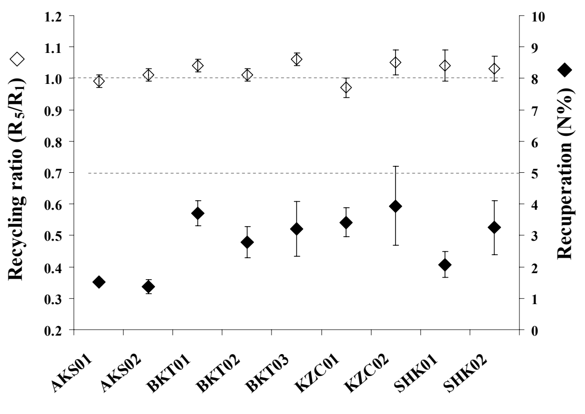

Fig. 4. *Recycling ratios and recuperation values (average of six aliquots) corresponding to natural dose estimates obtained using the SAR protocol for each sample. Open diamonds represent the recycling ratio and the dashed line shows the unity recommended for recycling ratios. Filled diamonds show the recuperation values, the upper limit recommended is indicated by the dashed line.*

possible with the combination of OSL ages and obtained data from a geological survey which is currently underway.

Another interesting result from the dating of samples is the data from the sample Aksalur 2 which belongs to very well sorted loess deposits formed by eolian activity.

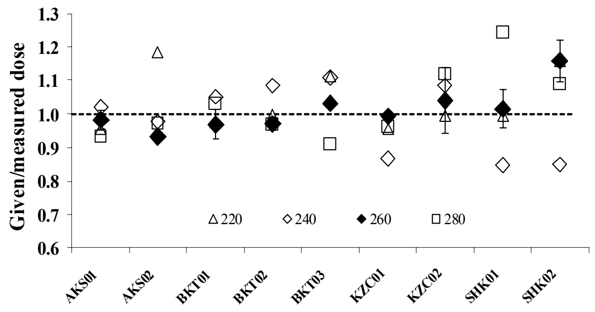

Fig. 5. *Dose recovery results for all samples. Given to measured dose ratio values are shown for different preheat temperatures between 220-280°C.*

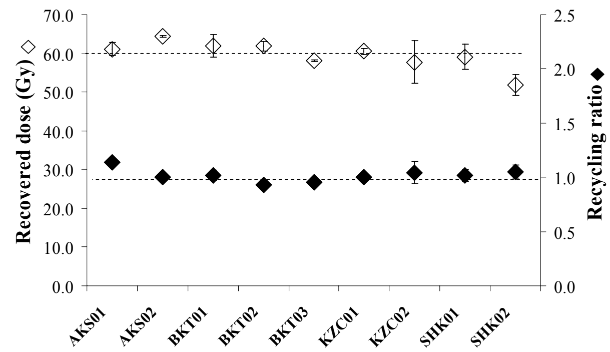

Fig. 6. *Recovered doses from a laboratory dose of 60 Gy measured at 260°C preheat temperature. The values of recovered doses are shown as open diamonds and the average value of all is shown as the dashed line. The filled diamonds represent the relevant recycling ratios from each sample averaged of three aliquots. The dashed line indicating the unity is recommended for the recycling ratios.*

The 18-20 ka age of this deposits very well corresponds to the documented loess deposits from all over Mediterranean and Europe (Haase *et al.*, 2007; Bolikhovskaya and Molodkov, 2006) and also climatic conditions extracted from GRIP and GISP deep Greenland ice cores (GRIP Project Members, 1993).

We have no independent age control (i.e. radiocarbon method) due to the lack of suitable materials in the sediments such as fossils of wood. Furthermore the ages of some samples (Bektemur 97-109 ka) were beyond the detection limit of radiocarbon method.

5. CONCLUSION

We applied successfully a modified SAR protocol with IR treatment as suggested by Wallinga *et al.* (2002) on feldspar contaminated quartz samples. Although the lack of independent age control we can summarize the following reasons why the OSL-SAR ages presented in **Table 2** can be taken into account.

1. All values of D_e were below the upper dose limit deduced from the growth curves constructed for all sediment samples.
2. The equivalent dose values were consistent with stratigraphy.
3. Recycling ratio and recuperation values in all measurements were satisfactory (as internal checks of reliability).
4. The age of aeolian deposits from Aksalur (18 ka age) is in good agreement with the age of documented loess deposits from all over Mediterranean and Europe.

The ages presented here provide clues for understanding the possible dynamics controlling the drainage evolution of the area as well as the tectonic slip and uplift rates. A wide scale geological study is currently going on and the final geological evaluation will be possible when these OSL results are combined with the data from this geological survey.

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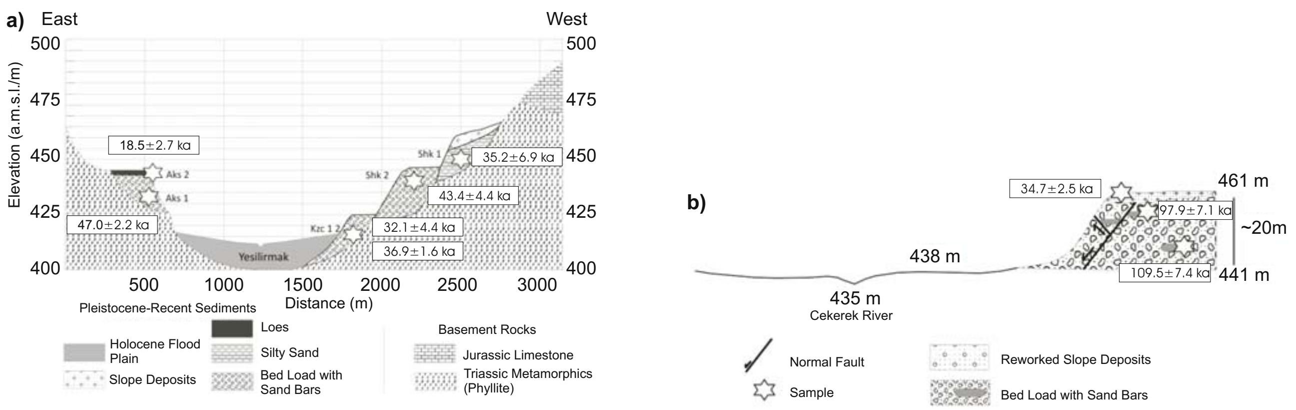

Fig. 7. *Schematic view of the stratigraphy for the terrace sediments showing locations (open stars) and obtained OSL ages in ka; (a) Aksalur, Kizilca and Sahinkaya (b) Bektemur.*

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