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Impact of climate change and Quaternary tectonic uplift on the development of terraces, Kâhta and Göksu stream, Adıyaman (SE Türkiye)

Kâhta ve Göksu Çayı Taraçalarının OSL Yaşlandırması ve Taraçaların Gelişiminde İklim Değişmeleri ve Tektonik Hareketlerin Etkisi (Güneydoğu Türkiye/Adıyaman)

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A B S T R A C T / *Ö Z*

In this study, optically stimulated luminescence (OSL) dating of terraces formed by the Kâhta and Göksu streams, which are located in the Adıyaman Basin and are not flooded by Atatürk Dam Lake, was completed for the first time. The rate of uplift along with the effect of climate change on the formation of these terraces were revealed, so a definite scientific contribution was made to the dating of uplift in the region. The streams, the most important tributaries of the Euphrates River, are fed from the Southeastern Taurus Mountains. The data in this study clearly supported that the terraces in the study area are present in similar river basins on the south side of the entire Southeast Anatolian Thrust and similar uplift was seen in these areas. This region continued to rise in the Late Pleistocene-Present time interval. From field studies, 5 terrace systems were identified in the Kâhta and Göksu Stream valleys at different altitudes. The samples taken from the terraces were dated by the OSL method and the stages of erosion and accumulation were determined. Accordingly, the Kâhta Stream terraces formed 128.53ka, 37.31ka, 20.13ka, 9.69ka, 5.36ka years ago, respectively, and the Göksu Stream terraces formed 83.45ka, 31.43ka, 19.58ka, 13.27ka, 7.94ka years ago, respectively. The effect of climate change is evident in the formation of T1 and T3 terraces and their incision by the streams. In addition, the reason why the terraces to the north are located 50 m higher than those to the south is tectonic uplift due to southward thrusts in the Eastern Taurus Orogenic Belt. In light of these data, the tectonic uplift rate for the study area and its immediate surroundings is 0.5 mm/yr.

Bu çalışmada, Adıyaman Havzası'nda yer alan ve Atatürk Baraj Gölü'nün altında kalmayan Kâhta ve Göksu derelerinin oluşturduğu taraçaların optik uyarılmış lüminesans (OSL) tarihlemesi ilk kez tamamlanmıştır. Bu taraçaların oluşumunda yükselme hızı ve iklim değişikliğinin etkisi ortaya konulmuş, böylece bölgedeki yükselmenin tarihlenmesine kesin bilimsel katkı sağlanmıştır. Bu çalışmadaki veriler, çalışma alanındaki taraçaların tüm Güneydoğu Anadolu Bindirmesi'nin güney yakasındaki benzer akarsu havzalarında bulunduğunu ve benzer yükselmenin bu alanlarda görüldüğünü açıkça desteklemektedir. Bu bölge Geç Pleyistosen-Günümüz zaman aralığında yükselmeye devam etmiştir. Arazi çalışmalarından Kâhta ve Göksu Çayı vadilerinde farklı yüksekliklerde 5 adet taraça sistemi tespit edilmiştir. Taraçalardan alınan örnekler OSL yöntemi ile tarihlendirilmiş, aşınma ve birikme dönemleri belirlenmiştir. Buna göre Kâhta Çayı taraçaları sırasıyla 128.53ka, 37.31ka, 20.13ka, 9.69ka, 5.36ka yıl önce, Göksu Çayı taraçaları ise sırasıyla 83.45ka, 31.43ka, 19.58ka, 13.27ka, 7.94ka yıl önce oluşmuştur. T1 ve T3 taraçalarının oluşumunda ve akarsular tarafından kesilmesinde iklim değişikliğinin etkisi belirgindir. Ayrıca kuzeydeki taraçaların güneydekilerden 50 m daha yüksekte yer almasının nedeni Doğu Toros Orojenik Kuşağı'nda güneye doğru itilmeler sonucu oluşan tektonik yükselmedir. Bu veriler ışığında çalışma alanı ve yakın çevresi için tektonik yükselme hızı 0,5 mm/yıl olarak hesaplanmıştır.

1. Introduction

As with fluvial deposits and geomorphological features that occur as a result of internal and external processes, fluvial terraces contain records of geological processes (Schumm, 1977). The most basic factors affecting the formation of stream terraces are events occurring at different times such as tectonic activity, climate change and base level change (Bridgland, 2000; Vandenberghe & Maddy, 2001; Vandenberghe, 2002). The incision and accumulation that occurs as a result of climate change causes changes in the flow rate of streams and sediment transport. These processes can explain the development of terraces in areas where tectonic activity is slow. However, the formation of multi-period terraces cannot be explained only by climate change (Bull, 1990; Xu & Zhou, 2007). Due to this general situation, tectonic movements and climate change are decisive for the development of terraces.

In most of the studies conducted on terraces, it is accepted that tectonic movements are dominant. However, it is generally known that climate change in the Quaternary period was effective on the formation of terraces (Bridgland, 2000; Starkel, 2003; Vandenberghe, 2007; Bridgland & Westaway, 2008).
The Kâhta and Göksu stream valleys are located in a tectonically active area, allowing both climatic and tectonic influences to contribute to the development of terraces in the study area (Fig. 1). Considering the studies conducted in Southeastern Anatolia, the tectonic movements in the region started in the Late Cenozoic and intensified in the Late Miocene-Pliocene (Demir et al., 2007a, 2007b, 2008; Westaway et al., 2009a; Trifonov et al., 2018).

In studies conducted in Southeastern Anatolia, the terrace formations were attributed to the entire Late Cenozoic period (Demir et al., 2007a, b, 2008, 2012; Trifonov et al., 2018). Since Pliocene and Quaternary terraces were evaluated in the studies with this scope, the number of terraces is increasing. For example, Demir et al. (2007a) determined six terraces around the Karababa Bridge downstream of Atatürk Dam. Wilkinson (1990) identified eight terraces (160 m, 125 m, 100 m, 45 m, 15 m, 8 m, 2 m and 1 m) on the floodplain of the Euphrates River.

Since it is easier to obtain data for dating from the main valley of the Euphrates, researchers have mostly conducted studies of the main valley rather than the tributaries (Demir et al., 2007a, b, 2008, 2012). Trifonov et al. (2018) studied the development of the Euphrates valley in the Pliocene and Early Pleistocene periods on a regional scale. Ozherelyev et al. (2019) compared paleolithic findings in the Euphrates River basin with terraces in four locations in the lower basin of Göksu stream and dated the terraces.

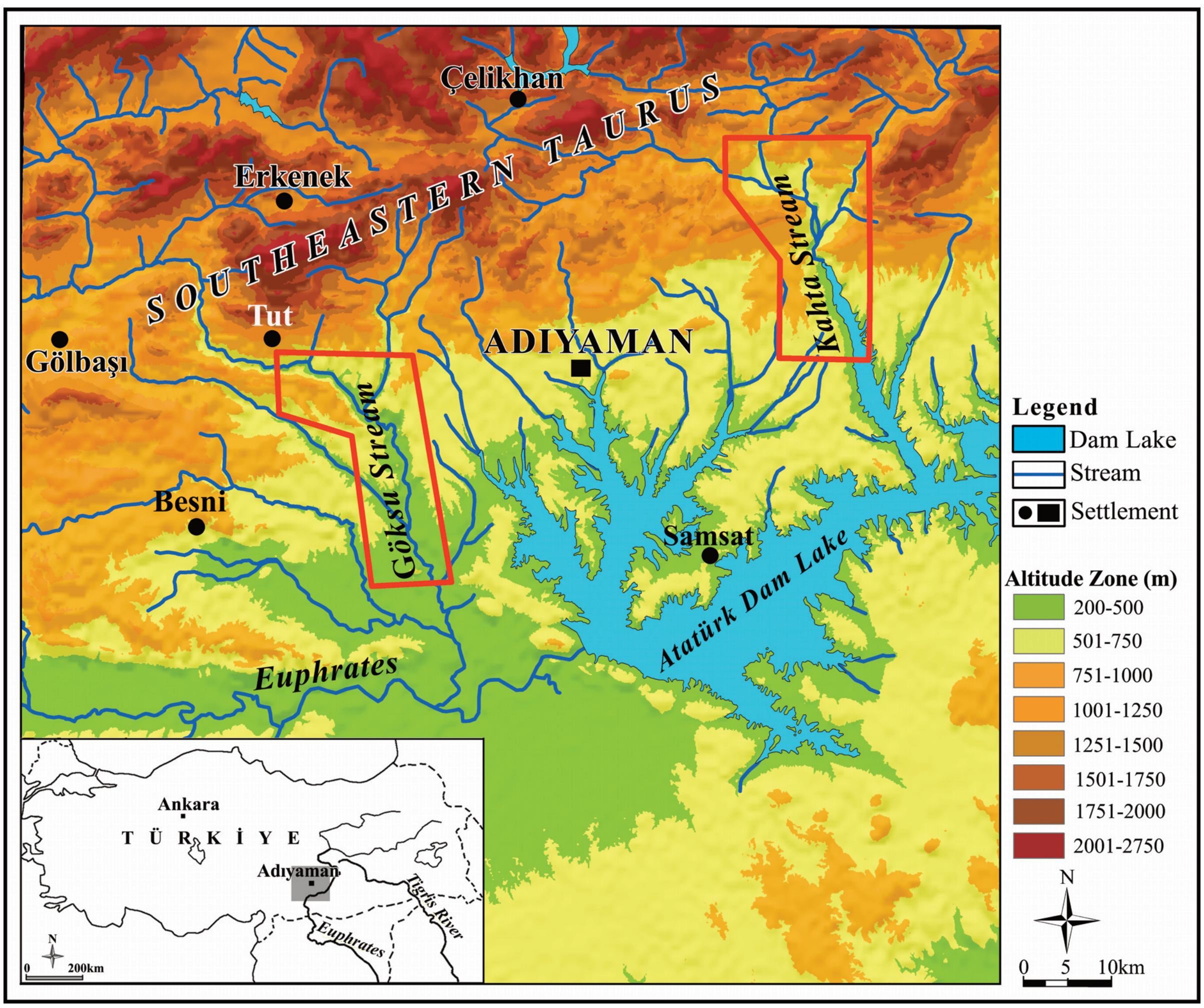

Figure 1. Location map for the Kâhta and Göksu streams.

Kâhta and Göksu streams are located in the southeast of Türkiye, in the north of the Adıyaman Basin. The streams, which are sourced in the Southeastern Taurus Mountains, constitute the most important tributaries of the Euphrates River in Southeastern Anatolia (Fig. 1). After the construction of Atatürk Dam, the largest dam lake in Türkiye, a large part of the Adıyaman Basin and many terraces of the Euphrates River in the Adıyaman Basin were flooded by the dam lake. However, most of the terraces of the Kâhta and Göksu streams are still at the surface. The Kâhta and Göksu stream basins are located in an area that is very sensitive to climate change in the Quaternary period. This study was carried out in order to correlate the formation of terraces and climate change. For this purpose, the Quaternary terraces were mapped, OSL dating was performed to determine the formation periods of the terraces, and the formation processes of the terraces were determined by correlating the age results with climate change. Thus, the effect of tectonics on the formation of terraces along with climate change was revealed. As a result, total tectonic uplift and the uplift rate during the Late Pleistocene-Present in and around the study area were revealed by OSL dating, implemented in this study for the first time.

2. Geomorphological and Geological Settings of The Basin

The Adıyaman Basin is bounded by the Southeastern Taurus Mountains, with an average elevation of 2000 m, from the north and extends NE-SW. This basin is 35-40 km at its widest part and is 70-75 km in length (Karadoğan & Tonbul, 2013). The Kâhta and Göksu stream valleys have rugged topography that is highly deformed by younger tectonic movements. The northern parts of both valleys are cut by the East Anatolian Fault (EAF), and the southern part is cut by the Adıyaman Fault (AF). Due to these tectonic structures and the influence of the Southeast Anatolian Thrust, the basin is very congested and fragmented. With regional-scale tectonic movements, mountainous areas formed to the north, and basins formed to the south. Different landforms are seen in and around the basin, which is deeply divided by the Euphrates River and its tributaries. In addition, sediments eroded from mountainous areas in the north of the Adıyaman Basin were deposited on the valley floor in areas where the slope decreased. Later, these sediments were incised by Kâhta and Göksu streams and terraces formed.

Metamorphic rocks from the Paleozoic-Mesozoic period and igneous rocks from Mesozoic period outcrop in the north of the Adıyaman Basin. Anticlines, which are cut by faults from north to south, consist of Eocene limestones. Upper Miocene, Pliocene and Quaternary units are exposed in synclinal basins in the folded areas to the north and in the area corresponding to the flat Adıyaman Basin to the south (Fig. 2). The unit consisting of conglomerate, sandstone, mudstone and claystone successions from the Upper Miocene-Pliocene period has the largest outcrop area in the Adıyaman Basin. This unit, which is widely seen in the Southeastern Anatolian Region, was defined as the Şelmo Formation (Yılmaz & Duran, 1997; Öğrenmiş, 2006).

The area where the Adıyaman Basin is located has a rather complex and active character from a tectonic point of view within Southeastern Anatolia. In the north of the Adıyaman Basin, the Southeastern Anatolian Thrust (SEAT), the Eastern Anatolian Fault Zone (EAFZ) and the Adıyaman Fault Zone (AFZ) constitute the main tectonic structures, from north to south. Apart from these tectonic structures, the basin is bounded from the west by the Bozova Fault (Fig. 2).

Left lateral strike-slip faults with NE-SW strike are located in the Adıyaman Fault Zone (AFZ). This fault zone, which is accepted as a shear fracture of the EAF, separates from the EAFZ west of Palu town and deflects to the southwest. This fault continues towards Adıyaman, passing through the villages of Helindir and Hazar, located to the south of Hazar Lake. This fault is a left lateral strike-slip fault zone with a width of about 3 km and a length of 210 km with a direction of N60OE. The AFZ, located between Palu in the northeast and Besni (Adıyaman) in the southwest, consists of a series of parallel and semi-parallel fault segments. It passes through the center of Adıyaman province, and terminates after incision in the south of Besni town (Fig. 2; Perinçek et al., 1987; İnceöz et al., 2003).

2.1. Drainage characteristics of Kâhta and Göksu streams

In the Adıyaman Basin, all the streams in the north of Atatürk Dam Lake flow approximately from northwest to southeast (Fig. 1, 2). Kâhta and Göksu streams are the most important tributaries of the Euphrates River. Upper catchments of these streams located in the mountainous area and the distributaries located in the basin have different morphological features. Streams that follow fault lines in mountainous areas formed narrow and deep valleys. The valleys of these streams expand towards the Adıyaman Basin and show a broad-base valley feature. In addition, meander features formed in some parts of the Kâhta and Göksu Stream valleys, and deep gorges formed in areas where anticlines were cut.

2.2. Characteristic features of the terraces of Kâhta and Göksu streams

The development of Kâhta and Göksu streams is evaluated within the development of the Euphrates River. According to fieldwork it was seen clearly that the Euphrates system was incised into its own bed in a meandering style due to changing climate and regional uplift in the Pleistocene. According to Erol et al. (1987), this incision had different periods under the influence of Pleistocene climatic fluctuations. A valley floor developed during each pause period, during periods when incision accelerated, these bases were incised and four main terraces (T1-T4) formed. Of these terraces, those belonging to the Lower Pleistocene are located 80-100 and 50-70 m higher than the present day valley floor, and the terraces from the Middle and Upper Pleistocene are located 25-30 and 10-15 m higher. This classification for the terraces of the Euphrates River is considered the most basic classification. Karadoğan & Tonbul (2013) used the classification applied by Erol et al. (1987) for the terraces of the Euphrates River in the Adıyaman Basin. In all of these studies, the Quaternary terraces were taken into account. Erol (1983) explained the neotectonic development of Türkiye during the Late Miocene, Pliocene and Quaternary periods in the form of significant stages of erosion and accumulation. Accordingly, erosion and accumulation processes dominate until the Quaternary, and the development of stream terraces dominates in the Quaternary. Considering this point of view in the geomorphological development of Türkiye, Quaternary terraces have generally been studied. However, recent studies of these terraces were extended to cover the Cenozoic era and the number of terraces are known and at different altitudes (Wilkinson, 1990; Demir et al., 2007a, 2008, 2012; Westaway et al., 2009a; Trifonov et al., 2014).

In this study, 5 terraces were identified in the Kâhta and Göksu stream valleys included in the Euphrates River system (T1 90-120 m; T2 50-70 m; T3 30-40 m; T4 10-20 m; T5 3-5 m). Although the Quaternary terraces were examined in this study, more terraces were identified than the number determined by Erol et al. (1987).

3. Method

The OSL method was used to date the Kâhta and Göksu stream terraces. This method is widely used for the dating of terraces in different regions of the world and the results are considered reliable (Kıyak & Erturaç, 2008; Jia et al., 2015). In order to determine the geomorphological characteristics of the Kâhta and Göksu stream terraces, satellite image analyses and detailed fieldwork studies were carried out. During field work, terrace deposits were determined by geomorphological and sedimentological studies. The global positioning system (GPS) was used to measure the altitudes of the terraces, and laser meter and tape meter were used to measure thickness of the deposits. These measurements were made on deposits that were not destroyed as a result of human activities.

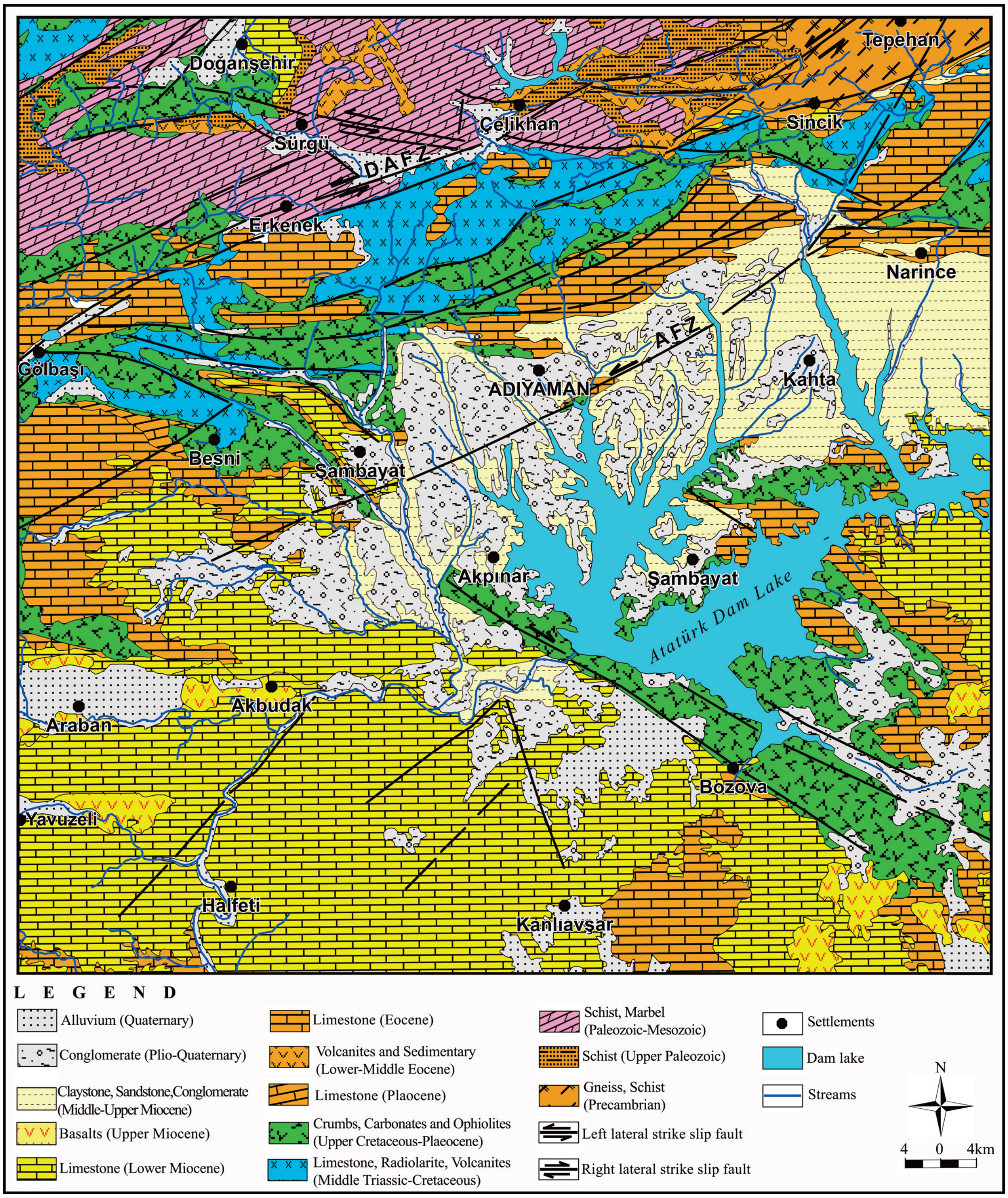

Figure 2. Geological map of the Adıyaman Basin (General Directorate of Mineral Research and Exploration (2002), 1/500 000 scale Geological Maps of Türkiye, Hatay and Sivas sheets).

During our geomorphological studies, it was determined that the terraces concentrated in the lower basins of the streams. In these locations, the areas to be sampled for OSL dating were determined by fieldworks conducted at different visits. For sampling, the lower and upper levels of the terraces were preferred since they contain fine sand and clay layers that are suitable for dating. In addition, in areas where the upper levels of alluvial deposits were destroyed due to their use as building materials, it was possible to take samples from the middle levels. After field examinations, 9 samples were taken from different altitudes and steps of terraces in the Kâhta Stream Valley and 7 samples were taken from the Göksu Stream Valley (Table 1). Attention was paid to the fact that the samples taken from both stream valleys correspond to the same terraces and close altitudes.

The equipment used in the sampling and the procedure are in accordance with the procedure for sampling for OSL dating. These are; 1) the GPS coordinates and elevations characteristics of the point to be sampled were recorded first. 2) Alluvium on the surface was cleaned to a depth of 20-30 cm at the point where the sample was to be taken. 3) A thick and double-layer black curtain with a width of 3 m, a length of 5 m was placed on the cleaned area. 4) In order to prevent the curtain from direct sunlight, it was fixed with iron stakes and also held by people around. 5) The sampling researcher entered the curtained area and cleaned the surface for at least another 20 cm. 6) After this final cleaning, two different samples of 1-2 kg were taken and placed in pre-prepared double-layered, light-proof black bags. 7) The samples were labeled and stored in closed boxes.

Table 1. GPS locations for samples of Kâhta and Göksu stream (Adıyaman) terraces (37 K).

Location	Sample code	Sampling Location	X coordinate	Y coordinate	Elevation (ASL) (m)
Kâhta	**KHT-1**	Cendere Bridge South (T3 central section)	465686E	4198342N	622
	KHT-2	Cendere Bridge South (T3 the lowest section)	465748E	4198217N	601
	KHT-3	Burmapınar district (T2 the lowest section)	465998E	4198962N	661
	KHT-4	Cendere Bridge opposite (T3 middle section)	466513E	4198158N	644
	KHT-5	South of Erikdere (T1 middle-upper section)	467835E	4186725N	572
	KHT-6	Erikdere (T4 uppermost section)	467217E	4187523N	597
	KHT-7	Plain concrete sand construction site (T5 upper section)	466884E	4189910N	544
	KHT-8	Kâhta Bridge sand quarry (T2 the lowest Section)	467069E	4191472N	558
	KHT-9	Kâhta Bridge sand quarry (T2 upper section)	467199E	4191374N	593
Göksu	**GKS-1**	North of ÇİMKO (T3 upper section)	419110E	4172980N	531
	GKS-2	North of ÇİMKO (T2 lower section)	419291E	4173054N	509
	GKS-3	North of ÇİMKO (T2 lower section)	416376E	4175005N	532
	GKS-4	North of ÇİMKO (T3 upper section)	416331E	4174859N	553
	GKS-5	North of ÇİMKO (T5 upper section)	419065E	4173274N	509
	GKS-6	Höyük Altı (T1 the lowest section)	420155E	4162973N	465
	GKS-7	Göksu Vadi Tabanı (T5 upper section)	467552E	4191488N	450

Due to the fact that the sediment forming the terraces on Kâhta and Göksu Stream is well compacted and consists of hard pebbles, steel tubes could not be used for sampling. The hard pebbles contained in the alluvium prevented the penetration of the steel tubes and it was decided that the sample could be taken with the curtain covering method due to deterioration of the sample.

3.1. Analyses

In dating studies, the initial part of the OSL signal coming from quartz or feldspar grains as a measurement sequence is used as a single-part regenerative dose (SAR) protocol (Murray & Wintle, 2000). The samples to be used for OSL dating were sent to Işık University, Archaeometry Research Laboratory for ICP-MS analysis. In these analyses, the ratios of uranium (U), thorium (Th) and potassium (K) were determined (Table 2).

The uranium, thorium and potassium levels in the samples were measured using an element mass spectrum analyzer. In OSL dating, the environmental dose rate is calculated according to the conversion rate between the concentration of uranium, thorium and potassium that quartz can absorb (Aitken, 1985, 1998). Using the separable peaks of the in-situ recorded spectra, radionuclide concentrations of U and Th series decay isotopes and potassium were calculated. Then, using the gamma dose rate and conversion factors, the contributions of the decay isotopes and potassium to the beta dose rate were revealed (Olley et al. 1996). As a result, the ages of the samples were calculated based on the equivalent dose and environmental dose ratios. However, due to the reaction of quartz in the terrace samples to radioactive rays, the error rate in the dating results was high. As the age increased, the error rate also increased.

4. Results

According to sedimentological and geomorphological studies carried out in the Kâhta and Göksu Stream valleys, 6 terraces were identified in the lower reaches of these streams at different altitudes with respect to the valley floors. Of these, 1-2 m terraces were included in 3-5 m terraces and the number of terraces was reduced to five. The terraces are located at altitudes of T1 90-120 m, T2 50-70 m, T3 30-40, T4 10-20 m and T5 3-5 m relative to the valley floor. These situations in the terraces systematically change due to the tectonic uplift in the north of the Adıyaman Basin. This change is especially clear in the T1 terraces and they are 50 m higher than the terraces located to the south.

4.1. Formation, characteristics and OSL dating results for Kâhta Stream terraces

For OSL dating, 9 samples were taken from five terrace deposits with different heights in the Kâhta Stream Valley and 7 samples were taken from the terraces of the Göksu Stream. Since the terraces are spread over a very large area, the plan is to take more samples for dating. However, samples were taken from key areas according to geomorphological observations in order to avoid confusion about the costs and correlations of the samples. The points corresponding to the upper and lower levels of each terrace deposits were selected for sampling. However, it was possible to take samples from the upper and middle parts of some terraces. Thus, sampling was done from the same level terraces in both stream valleys and from the same altitudes relative to the valley floor.

There is a periodic correspondence between the development of the Kâhta and Göksu streams and the development of the Euphrates system. The two streams, which have a consecutive structure, were affected by climate change and tectonic movements in the Quaternary period. The fact that the streams are located on faulted zone in some areas and the presence of narrow points in the valleys show the tectonic effects. The formation of terraces by thick alluvial sediments along the valleys shows the effect of climate change.

Table 2. ICP-MS analysis results of samples from Kahta and Göksu stream terraces.

Sample Code	Cu	Pb	Zn	Ni	Fe	U	Th	Ca	Mg	Ti	Al	Na	K
	(PPM)	(PPM)	(PPM)	(PPM)	(%)	(PPM)	(PPM)	(%)	(%)	(%)	(%)	(%)	(%)
KHT-1	31.3	7.1	47	88.6	3.22	<0.5	2.5	4.68	1.76	0.192	1.63	0.02	0.13
KHT-2	29.7	7.5	37	84.0	2.51	0.6	2.9	3.70	1.56	0.173	1.42	0.02	0.09
KHT-3	32.9	7.2	51	109.6	2.95	<0.5	3.1	4.52	1.76	0.177	1.53	0.03	0.17
KHT-4	39.4	7.9	57	103.1	3.38	0.5	2.9	4.40	2.01	0.239	1.88	0.03	0.24
KHT-5	20.6	5.2	35	80.8	2.83	<0.5	2.8	10.96	1.05	0.120	1.68	<0.01	0.10
KHT-6	18.1	4.4	33	87.1	2.77	<0.5	2.1	10.62	1.13	0.120	1.48	<0.01	0.08
KHT-7	29.1	7.2	49	114.7	3.13	<0.5	3.6	2.50	1.58	0.181	1.92	0.01	0.18
KHT-8	37.8	4.9	52	129.9	3.45	<0.5	2.2	4.94	1.08	0.245	2.08	0.02	0.11
KHT-9	26.5	9.6	42	161.4	3.08	<0.5	2.3	10.68	1.14	0.137	1.84	<0.01	0.08
GKS-1	39.3	2.4	37	262.7	2.91	<0.5	0.6	6.50	2.98	0.161	2.14	0.15	0.09
GKS-2	31.0	2.3	37	378.7	2.88	0.6	0.8	6.44	3.05	0.142	1.83	0.09	0.08
GKS-3	32.4	2.3	37	242.4	2.84	0.8	0.8	5.43	3.06	0.152	2.04	0.15	0.08
GKS-4	38.0	3.3	38	174.8	3.24	<0.5	1.3	8.85	2.64	0.178	2.35	0.06	0.08
GKS-5	30.6	2.7	36	144.5	2.91	<0.5	1.1	6.31	2.35	0.163	2.30	0.24	0.12
GKS-6	25.7	3.1	29	331.9	2.31	<0.5	1.2	8.11	1.58	0.036	1.00	0.02	0.57
GKS-7	27.0	2.2	36	126.4	3.01	<0.5	0.8	5.63	2.08	0.181	2.04	0.19	0.08

Note: Rock Pulp samples were analyzed according to the 7AX Method.

Kâhta Stream joins the Euphrates River in the east of Adıyaman Basin. The Adıyaman Basin is located in an area that was very sensitive to climate change in the Quaternary period. Due to the location of the site, it is possible to make a correlation between the formation of terraces and climate change.

The terraces in the Adıyaman Basin and the Euphrates Valley and the terraces of the Kâhta Stream have very complex structure. The terraces of Kâhta Stream are characteristically seen in basins to the north and south of Yarlıca Mountain (Fig. 3). According to studies carried out throughout the region and detailed field studies carried out in the lower basin of the Kâhta Stream, 5 terraces were identified in the Kâhta Stream Basin. These are located at heights of T1 90-120 m, T2 50-70 m, T3 30-40, T4 10-20 and T5 3-5 m above the valley floor (Sunkar & Karataş, 2012, 2014; Fig. 3).

OSL dating was performed by taking 9 samples representing 5 terraces on 5 profile lines in the area where terraces are typically seen between Cendere Bridge in the Kâhta Stream valley and Atatürk Dam Lake (Table 3).

According to the OSL age data, the oldest age was obtained from the KHT 5 sample taken from the lower parts of T1 terrace near Erikdere in the northeast of Kâhta (Fig. 4). The KHT 3 sample taken for OSL dating of the T2 terrace was taken from the lower parts of the T2 terraces in the Burmapınar district, located to the south of Cendere Bridge (Fig. 5). The KHT 9 sample, which constitutes the second sample, was taken from the upper part of the T2 terrace to the east of Kâhta Bridge (Fig. 6). Since the T3 terraces in the Kâhta Stream valley are very wide and seen at different altitudes, more samples were taken from this terrace step. KHT2 and KHT8 samples were taken from the lower sections of T3 terrace cropping out south of the Cendere Bridge, with KHT4 sample taken from the middle levels, and KHT 1 sample from the upper section (Fig. 7). In the south of Erikdere, KHT 6 sample corresponds to the T4 step and it represents the uppermost part of this terrace (Fig. 8).

Table 3. Altitude, age and location data for Kâhta Stream terraces compared to the valley base.

Terrace	Altitude above stream (m)	Age (ka)	Sample code and location	MIS
T1	65	128.53±1.06	KHT-5. 467835E-4186725N	MIS 5e
T2	50	37.31±9.42	KHT-9. 467199E-4191374N	MIS 3
	55	23.85±2.72	KHT-3. 465998E-4198962N	MIS 2
T3	30	20.13±4.38	KHT-8. 467069E-4191472N	MIS 2
	40	12.85±1.71	KHT-4. 466513E-4198158N	MIS 1
	2	19.30±1.68	KHT-2. 465748E-4198217N	MIS 2
	25	9.69±1.88	KHT-1. 465686E-4198342N	MIS 1
T4	30	8.18±2.12	KHT-6. 467217E-4187523N	MIS 1
T5	5	5.36±0.72	KHT-7. 466884E-4189910N	MIS 1

4.2. Formation, characteristics and OSL dating results for Göksu Stream terraces

Göksu Stream is fed from mountainous areas in the east of Kahramanmaraş and joins to the Euphrates River in the west of the Adıyaman Basin. Göksu Stream, which is one of the important tributaries of the Euphrates River, is located on a tectonic line until the ÇİMKO Cement Factory. It turns south near the cement factory and joins the Euphrates River in the south of the basin. Because of this situation, the valley of the stream is asymmetrical in the north and a broad-based valley in the south (Fig. 9).

Due to the location of Göksu Stream in the region, it was affected by tectonic movements and climate change in the Quaternary. Due to this influence, similar terrace formations were defined at the same altitudes in this river valley as in other river valleys in the region. As with the Kâhta Stream valley, there are 6 terraces in the Göksu Stream valley. However, the last terrace was combined with the previous one and a 5 terraces system was identified. These terraces, which are located at the same altitudes as around the Kâhta Stream, are at altitudes of T1 90-120 m, T2 50-70 m, T3 30-40 m, T4 10-20 m and T5 3-5 m compared to the valley floor. With the effect of tectonics, the altitude of the terraces to the north of the cement factory is 20-30 m higher than the terraces to the south (Fig 9).

OSL dating was performed by taking 7 samples representing 5 terraces in 4 profile lines at different locations in the lower basin of the Göksu Stream valley where terraces are typically seen (Table 4).

Seven samples from different altitudes taken from the terraces of Göksu Stream were dates by the OSL method. According to the dating results, most of the terraces of Göksu Stream come from the Late Pleistocene period. According to OSL dating results, the oldest age result (83.45±8.79 thousand years) for the terraces of the Göksu Stream was for GKS 6 sample taken from the middle section of T1 terrace in the east of Yazıyalankoz district (Fig. 10). Samples GKS 3 for T2 terrace, GKS 1, 2 and 4 for T3, and GKS 5 for T4 were taken to perform OSL dating (Fig. 11, 12, 13). For T5 terraces, GKS 7 samples were taken from the terrace located close to the valley floor but 1-5 m above the valley floor (Fig. 14). GKS 5 and 7 samples taken from the lowest terraces were very close to each other in terms of age. However, considering the morphology and age data, the locations were evaluated as two different steps.

As a result of archeological research in the Euphrates River basin, Acheulean and Middle Paleolithic stone tools were found on the lower terraces of the Euphrates, south of the Taurus Mountains. By correlating the age data obtained from these tools with the terraces, the periods when the terraces were formed were determined (Ozherelyev et al., 2019). Age data obtained as a result of archeological findings and OSL age data are compatible. The age data for sample GKS 6, which corresponds to the middle part of the T1 terrace, is compatible with the Middle Paleolithic age determined by Ozherelyev et al. (2019) for the same area.

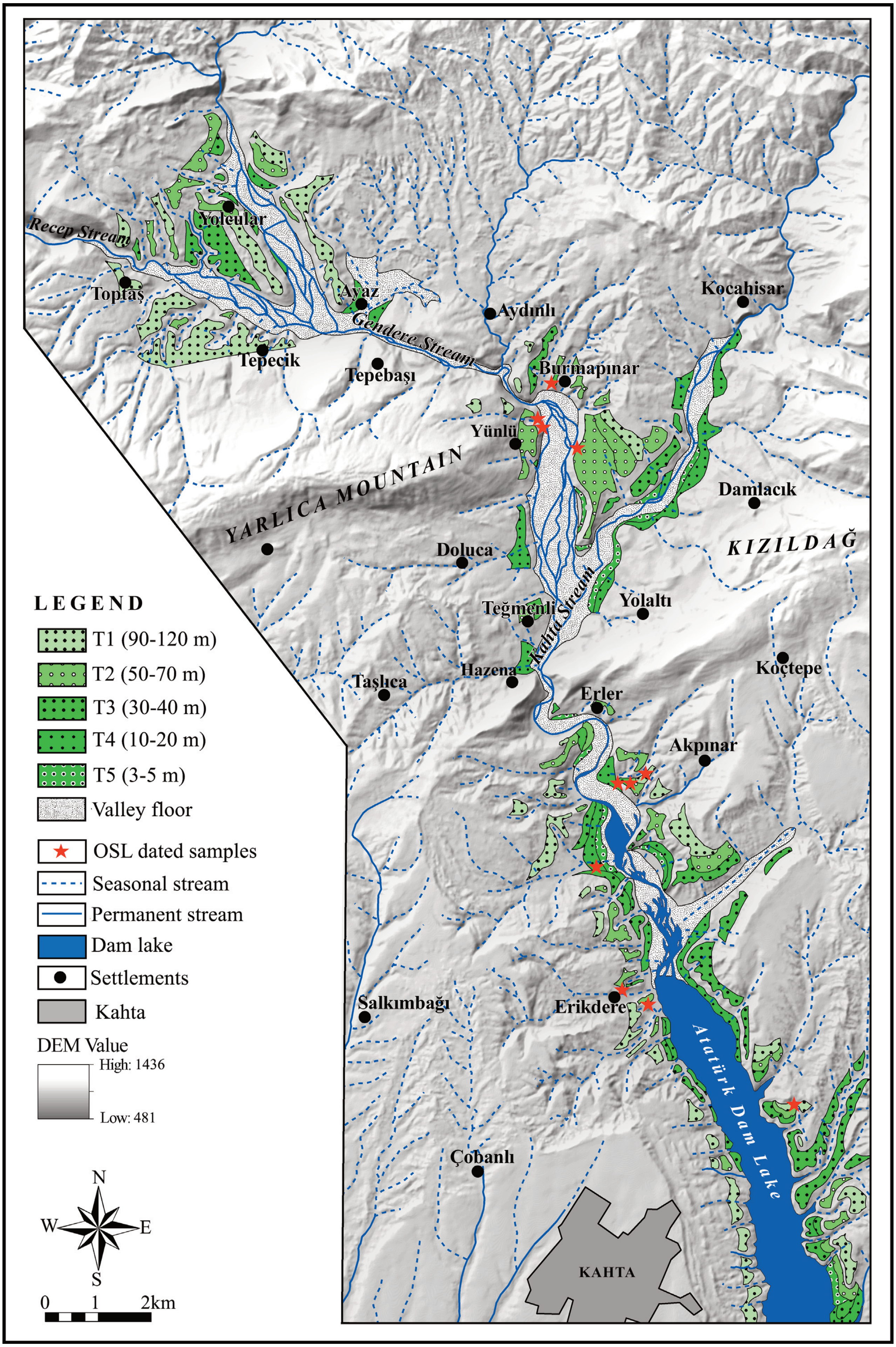

Figure 3. Areal distribution of the terraces in the lower reaches of Kâhta Stream (Sunkar & Karataş, 2012).

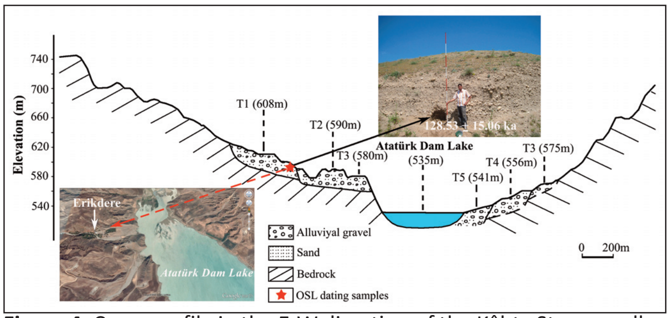

Figure 4. Cross profile in the E-W direction of the Kâhta Stream valley south of Erikdere, showing terraces and sample (KHT-5) locations

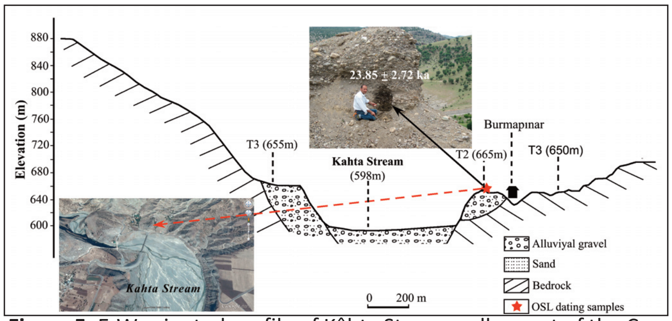

Figure 5. E-W oriented profile of Kâhta Stream valley east of the Cendere Bridge, showing terraces and sample (KHT-3) locations.

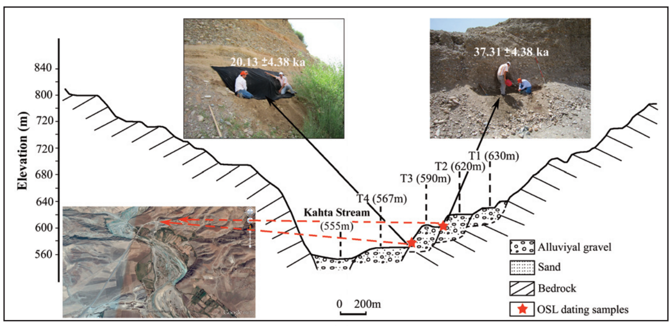

Figure 6. E-W oriented profile of the Kâhta Stream valley east of the Kâhta Bridge, showing terraces and sample (KHT-8, 9) locations.

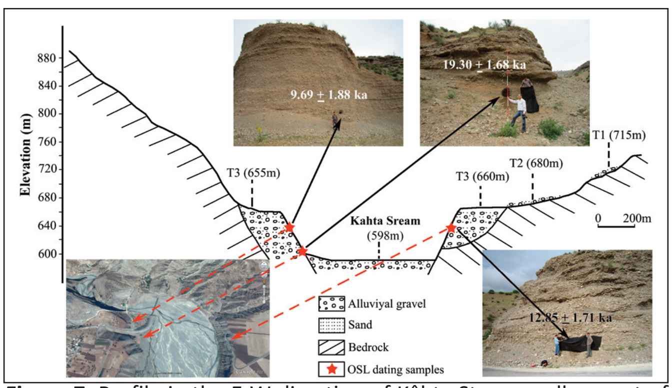

Figure 7. Profile in the E-W direction of Kâhta Stream valley west of the Cendere Bridge, showing terraces and sample (KHT-1, 2, 4) locations.

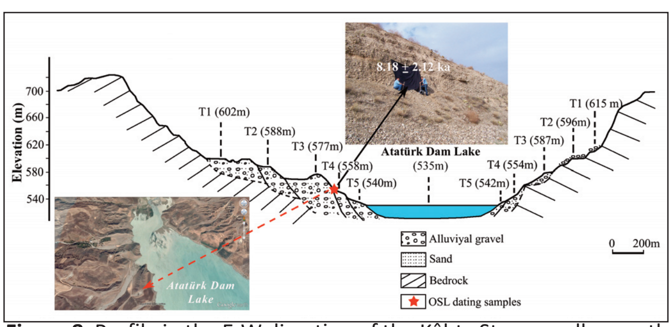

Figure 8. Profile in the E-W direction of the Kâhta Stream valley south of Erikdere, showing terraces and sample (KHT-6) locations.

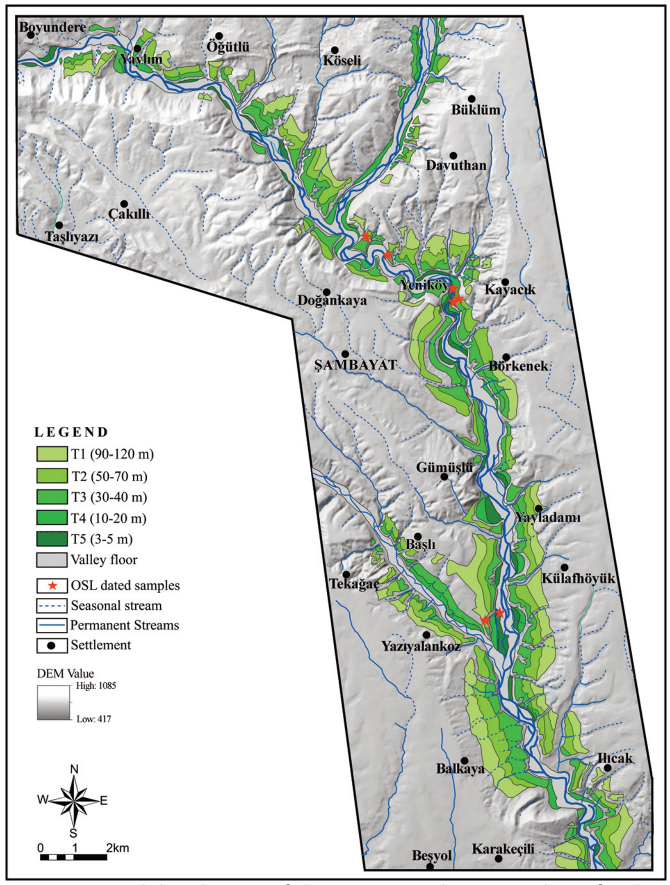

Figure 9. Areal distribution of the terraces in lower reaches of Göksu Stream (Sunkar, 2016).

Table 4. Altitude, age and location data for Göksu Stream terraces compared to the valley base.

Terrace	Altitude above stream (m)	Age (ka)	Sample code and locations	MIS
T1	45	83.45±8.79	GKS-6. 420155E-162973N	MIS 5a MIS 4
T2	30	31.43±3.87	GKS-3. 416376E-175005N	MIS 3
T3	15	25.92±2.59	GKS-2. 419291E-173054N	MIS 2
	20	19.58±2.84	GKS-4. 416331E-174859N	MIS 2
	25	13.27±2.64	GKS-1. 419110E-172980N	MIS 2
T4	5	9.25±2.42	GKS-5. 419065E-173274N	MIS 1
T5	2	7.94±1.18	GKS-7. 467552E-191488N	MIS 1

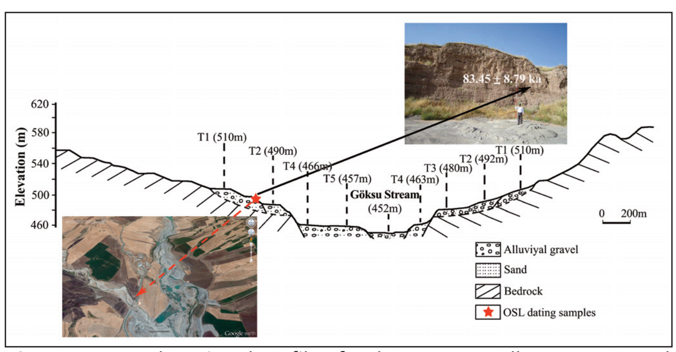

Figure 10. E-W directional profile of Göksu Stream Valley, terraces and sample (GKS-6) locations, east of Yazıyalankoz district.

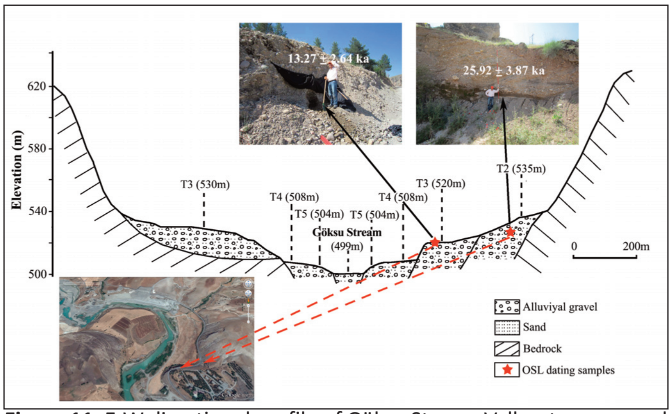

Figure 11. E-W directional profile of Göksu Stream Valley, terraces and sample (GKS-1, 2) locations north of ÇİMKO Cement Factory.

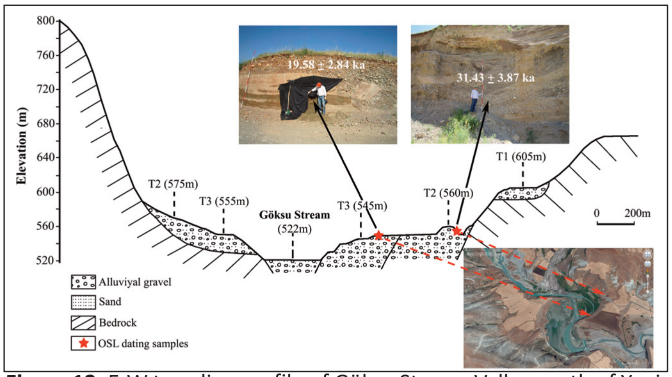

Figure 12. E-W trending profile of Göksu Stream Valley north of Yenikaş, terraces and sample (GKS-3, 4) locations.

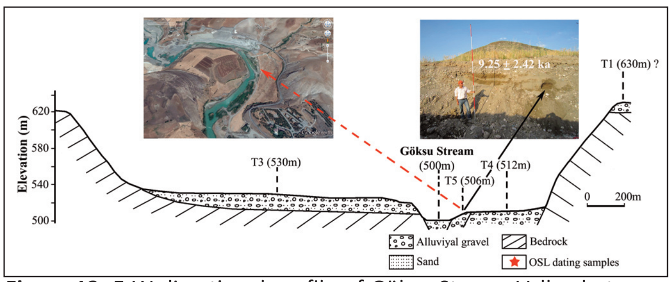

Figure 13. E-W directional profile of Göksu Stream Valley between ÇİMKO and Yenikaş, terraces and sample (GKS-5) locations.

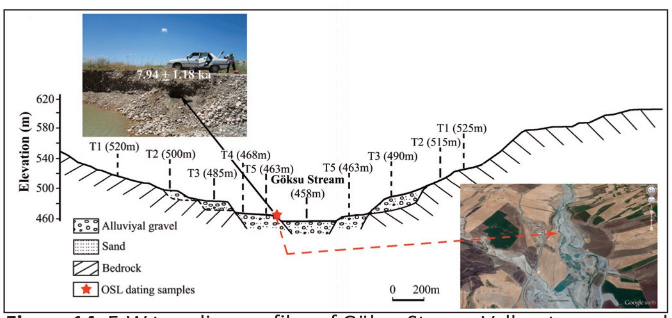

Figure 14. E-W trending profiles of Göksu Stream Valley, terraces and sample (GKS-7) locations southwest of Külafhöyük.

5. Discussion

Since Kahta and Göksu Streams constitute the two largest branches of the Euphrates, the terraces along these streams and the terrace systems identified in different locations in the Euphrates river system in Southeastern Anatolia, Syria and Iraq have similar characteristics in terms of their formation periods, altitudes from the valley floor and number of terraces (Wilkinson et al., 1990; Demir et al., 2007a, 2008, 2012; Westaway et al., 2009a,b; Trifonov et al., 2014). However, the terraces at different locations in the Euphrates river system are at different altitudes compared to the valley floor.

Taking these geomorphological features of the terraces into account, in NE Syria, (Demir et al. 2007a), in the Birecik region (Demir et al., 2008) and near Diyarbakır in the terraces of the Tigris River (Westaway et al., 2009b) where age data is provided by old basalt flows, it was stated that older gravel successions formed in the Early-Middle Pliocene period. In fact, the possibility of some successions dating back to the Late Miocene is accepted. In these studies, it was possible to reach older age data since samples were obtained from basalt flows.

However, in this study, the induced luminescence (OSL) method was used to date the terrace deposits, considering that the stratigraphically uppermost Plio-Quaternary conglomerates were incised in the Adıyaman Basin and the Kâhta and Göksu terraces began to form after this period. Since Kâhta and Göksu terrace deposits consist of well-washed sand and gravel, quartz was used to obtain OSL age data. Due to the reaction of quartz with radioactive rays, the error rate in the dating results was relatively high. The highest error rate was found for KHT 5 sample, the lowest error rate was for KHT 7 sample, and according to these data, an upward trend was seen in the error rate as the age data increased. The OSL dating of the GKS 6 sample, which corresponds to the T1 terrace along Göksu Stream, and the Middle Paleolithic age obtained by Ozherelyev et al. (2019) from archeological findings for the same area, show that the age data obtained in this study are correct.

While Kâhta and Göksu terraces are located in a tectonically active area, the effect of climate change and tectonic uplift is evident in the incision of the terraces. For this reason, it was difficult to determine the traces of tectonic uplift and climate change during formation of terraces. However, there are important data about the rate of tectonic uplift in regional studies. According to Demir et al. (2008), the amount of uplift from the Middle Pliocene to the present in southeastern Türkiye reached 300 m. In addition, it was stated that after the Late Early Pleistocene, the uplift increased and an estimated 110 m uplift occurred in this period.

Trifonov et al. (2018) stated that the Euphrates River found its main bed in the Taurus Mountains at the end of the Calabrian, about 800-900 thousand years ago. With the deposition of the youngest bed of the Euphrates, the older valley floors became higher terraces. After this period, the Taurus Mountains rose more than 330 m. This elevation rose approximately 0.13-0.16 mm annually in the north of the Taurus Mountains and 0.1 mm in the south. And also Göksu Stream terrace 3 (h=54-67 m; Early Middle Pleistocene) and Kahta Stream terrace 3, which is called Erikdere in the east of Kahta, have similar proportions (Trifonov et al., 2018).

There is not much difference between the regional scale uplift values of Demir et al. (2008) and Trifonov et al. (2018). However, the amount of elevation determined by Trifonov et al. (2018) for the Southeast Taurus is close to three times the regional uplift. Kâhta and Göksu Streams kept up with this rapid rise and incised the folds located to the north of Adıyaman by 110 m (Photo 1). Due to this incision and uplift, the T1 terraces of the Kâhta and Göksu Stream are 50 m higher than the T1 terraces in the south. When the tectonic uplift rate determined for the Southeast Taurus Mountains is compared with the oldest age data (KHT 5) obtained from the Kâhta terraces, tectonic uplift of 50 m occurred in approximately 130 thousand years. With this value, there is concordance between the amount of uplift determined by Trifonov et al. (2018) for the Southeast Taurus and the OSL dating obtained in this study. When the age data for the terraces in the south of the Taurus Mountains are compared with the incision values, the value is approximately 4 times higher than the regional scale uplift rate of Demir et al. (2008) and Trifonov et al. (2018). When the KHT 5 location is taken as reference, the effect comprises 25% due to tectonics and 75% due to climate change for formation of terraces in Adıyaman Basin.

The elevation data for the terraces and the OSL age results were used to determine the incision rates of the river terraces (Table 5). With this method, Jia et al. (2015) accurately determined the cleavage rates of terraces in northern China.

The values for Göksu Stream are as follows; in 83.45-31.43, 31.43-25.92, 25.92-13.27, 9.25-7.94 and 7.94 thousand year and 45 m-0.53 mm/year, 30 m-0.95 mm/year, 25 m-0.96 mm/year, 5 m-0.54 mm/year and 2 m-0.25 mm/year, respectively (Fig. 15).

When the incision rates and age relationship of the terraces on Kâhta and Göksu Streams are evaluated, some differences are observed, although they are generally compatible (Fig. 16). The fact that the incision rate for the terraces is higher than the tectonic uplift rate suggests the direct effect of climate change. As seen in Figure 16, there is a consistent relationship with the general trend as a result of the comparison of age data obtained from the terraces and data obtained from the Vostok and Greenland glaciers. The period when the first valley system was formed and the incision periods of the first terraces in both river valleys correspond to the high temperature drop between MIS 1 and MIS 2.

In this study, age, depth and incision rates in the Kâhta Stream terraces were 128.53-37.31, 23.85-20.13, 12.85-8.18, 8.18-5.36 and 5.36 thousand year and 65 m-0.50 mm/year, 50 m-1.34 mm/year, 30 m-0.14 mm/year, 25 m-3.05 mm/year and 5 m-0.98 mm/year, respectively (Fig. 16).

Due to tectonics, terrace deposits are located at an elevation of more than 120 m in some areas. In the south of Cendere Gorge, on Köprü Hill to the east of the gorge and on Kılavuz Hill to the east of this hill, the T1 terrace fillings, which are more than 5 m thick, are 150-160 m higher. This situation is related to the fault cutting the southern slopes of Yarlıca Mountain (Fig. 2; Photo 2).

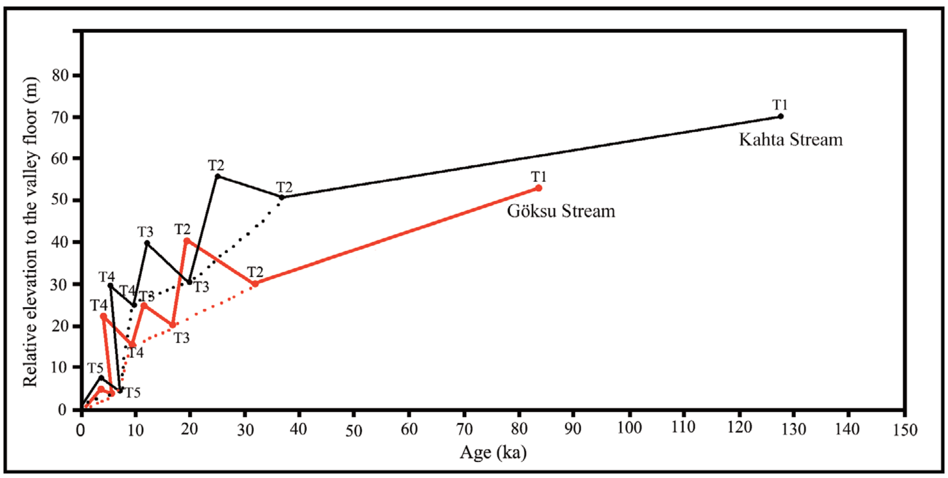

Figure 15. Age and altitude of the terraces on the Kâhta and Göksu streams relative to the valley floor.

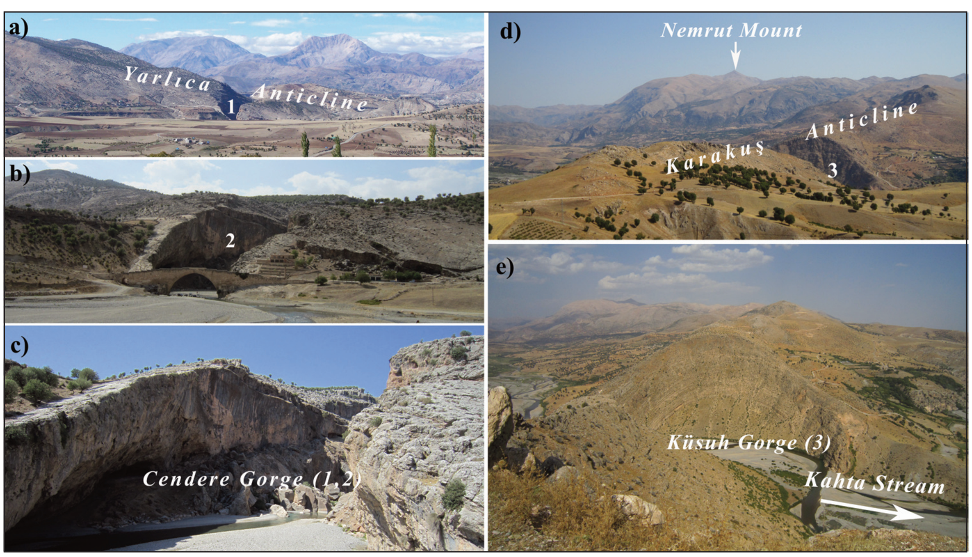

Photo 1. Cendere Gorge (a, b, c) formed by the incision of the Yarlıca anticline and the Küsuh Gorge (d,e) formed by the incision of the Karakuş anticline. Kâhta Stream, which formed the two gorges, incised the anticline by 110 m.

Table 5. Formation dates for Kâhta and Göksu Stream terraces.

Location	Terrace	Age (ka)	Terrace history: Process	Terrace history: Average sediment thickness/downcutting depth (m)	MIS	Remark
Kâhta Stream	T1	128.53±15.06-37.31±9.42	Aggradation-Incision	20.5	MIS 5e	River bed and flood plain sediment-Rock and sediment incision
				45.5	MIS 4	
	T2	37.31±9.42-23.85±2.72	Aggradation	10.5	MIS 3	River bed aggradation
		23.85±2.72-20.13±4.38	Incision	22.5	MIS 2	Rock and sediment incision
	T3	20.13±4.38-12.85±1.71	Aggradation	6.5	MIS 2	River bed aggradation
		12.85±1.71-8.18±2.12	Incision	15.5	MIS 1	Rock and sediment incision
	T4	8.18±2.12-5.36±0.72	Aggradation	4.5	MIS 1	Flood plain sediment
	T5	5.36±0.72 to now	Incision	10.5	MIS 1	Sediment incision
Göksu Stream	T1	83.45±8.79-31.43±3.87	Aggradation-Incision	10.5	MIS 5 a	River bed and flood plain sediment-Rock and sediment incision
				23.5	MIS 4	
	T2	31.43±3.87-25.92±2.59	Aggradation	7.5	MIS23	River bed aggradation
		25.92±2.59-19.58±2.84	Incision	15.5	MIS 2	Rock and sediment incision
	T3	25.92±2.59-13.27±2.64	Aggradation	4.5	MIS 2	River bed aggradation
		13.27±2.64-9.25±2.42	Incision	10.5	MIS 1	Rock and sediment incision
	T4	9.25±2.42-7.94±1.18	Aggradation	4.5	MIS 1	Flood plain sediment
	T5	7.94±1.18- to now	Incision	8.5	MIS 1	Sediment incision

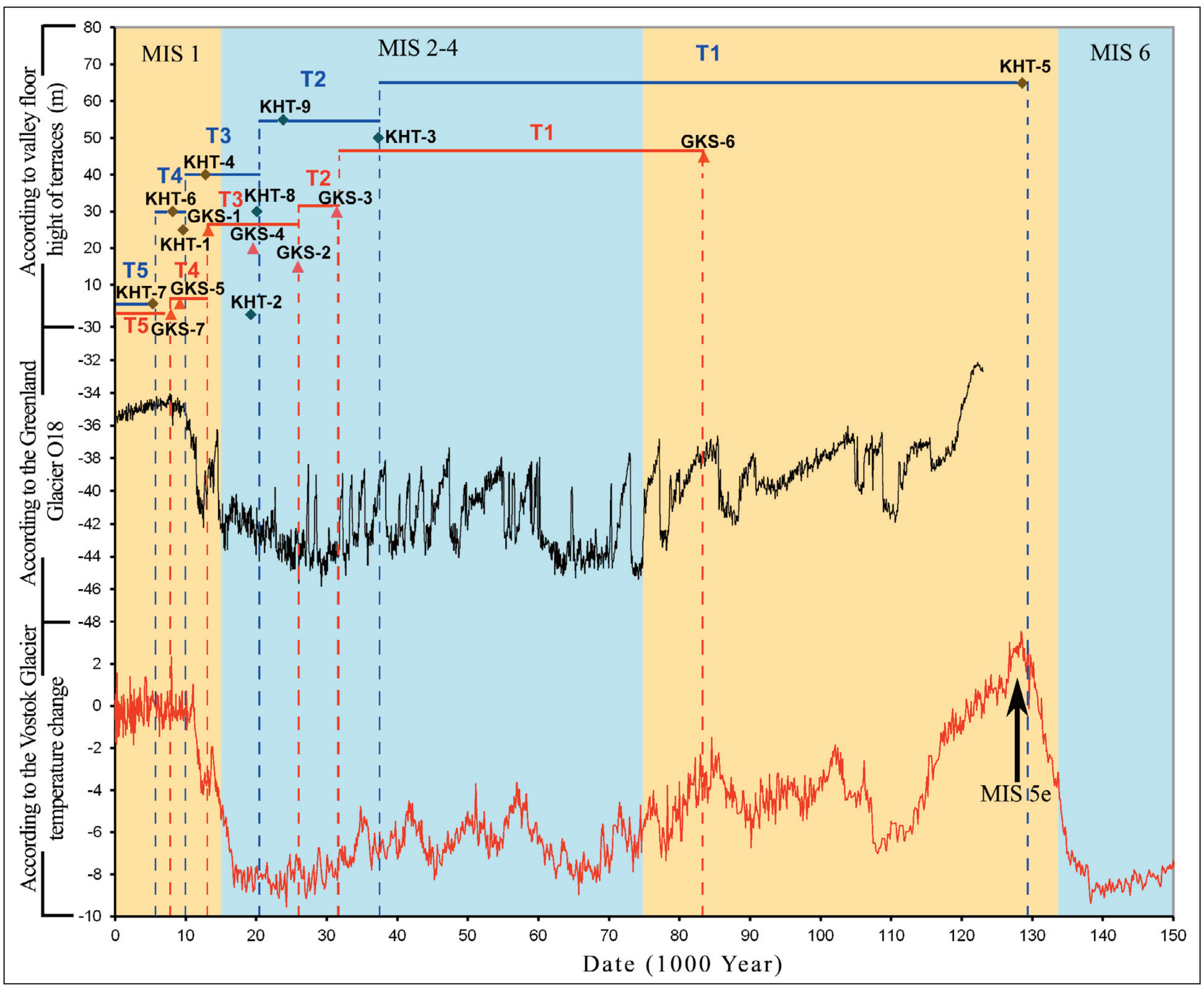

Figure 16. Relation of OSL age results for Kâhta (KHT) and Göksu (GKS) terraces with age data from Vostok (Jouzel et al., 1987) and Greenland glacier (Mörner, 1972).

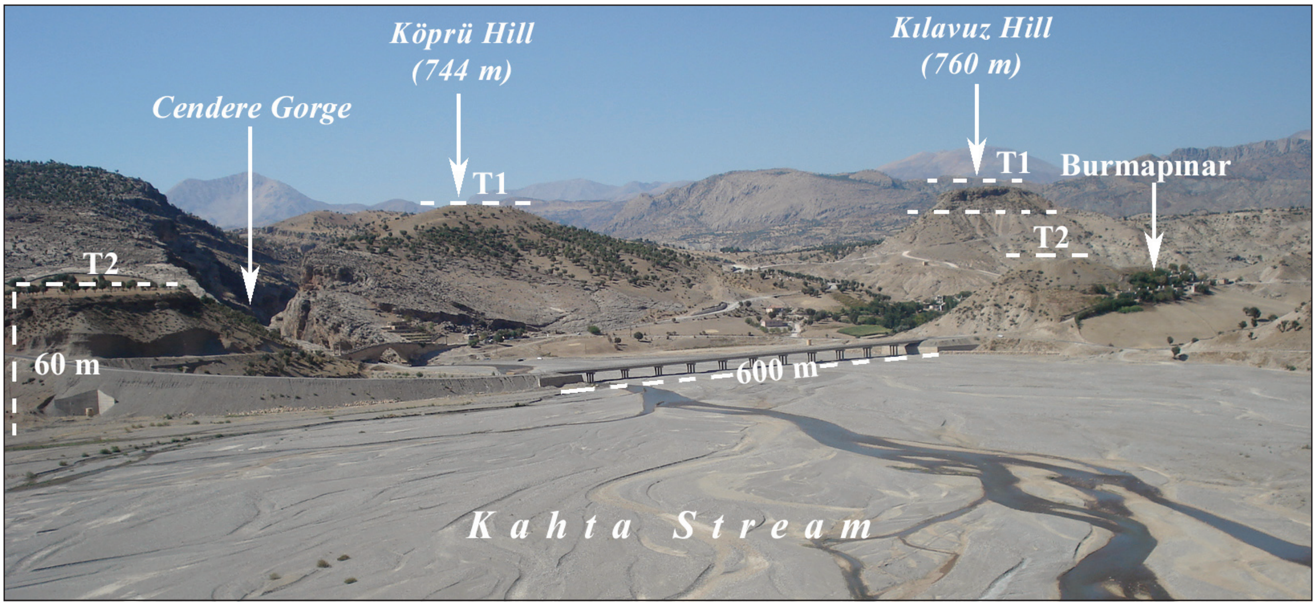

Photo 2. T1 sediments 150-160 m above the valley floor due to the tectonic effect near Köprü Tepe (744 m) and Kılavuz Tepe (760 m) east of Cendere Bridge.

6. Conclusions

Kahta and Göksu Stream terraces are located in the north of Adıyaman Basin, which was very sensitive to climate change in the Quaternary period. These two stream basins, which are included in the Euphrates River system, also flow along the Eastern Anatolian and Adıyaman fault zones, which are very active in terms of tectonics. Due to these features of the basins, the effect of climate change and tectonics on the formation of terraces is evident.

Five terraces were identified along the Kâhta and Göksu valleys. The altitude of these terraces relative to the valley floor were T1 90-120 m; T2 50-70 m; T3 30-40 m; T4 10-20 m; and T5 3-5 m, respectively.

The OSL dating of the Kâhta Stream terraces gave dates of 128.53-37.31, 23.85-20.13, 12.85-8.18, 8.18-5.36 and 5.36 thousand years for T1 to T5, respectively. These values for the terraces on the Göksu Stream were 83.45-31.43, 31.43-25.92, 25.92-13.27, 9.25-7.94 and 7.94 thousand years, respectively.

Kâhta and Göksu terraces developed as a result of tectonic uplift and climate change. In general, tectonic uplift caused the rivers to incise deeply, and climate change caused the accumulation of terrace fill. In addition, climate change and tectonic uplift were effective in the re-incision of the accumulated sediments. Particularly, the difference in incision values and ages is very high for T1 terraces. This difference is due to the obvious climate change between MIS 4 and MIS 5. A similar situation was also seen in T3 terraces. The effect of climate change between MIS 1 and MIS 2 is seen in the excessive incision of these terraces. The fact that climate change was more effective in this period caused the incision values of the terraces to be higher.

Tectonic uplift was revealed to be as effective as climate change for the formation of the terraces on Kâhta and Göksu Streams. The altitude difference of 50 m between the terraces close to the Taurus Mountain belt and those located in flat areas is directly related to tectonic uplift. T1 terraces are located 150-160 m above the valley floor on the rising block of the fault that cuts the southern slopes of Yarlıca Mountain near the Cendere Bridge in the Kâhta valley. This terrace is 50 m higher than the T1 (90-100 m) terrace further south. When the age data for the terraces are compared with the regional uplift rate, this value directly corresponds to the rate of uplift.

OSL dating revealed a more precise uplift rate of 0.50 mm/year for Kâhta Stream terraces and 0.53 mm/year for Göksu Stream terraces in the Late Pleistocene-Present time interval. When the age data for the terraces in the south of the Southeastern Taurus Mountains are compared with the incision values, a value approximately 3 times higher than the regional uplift rate emerges. When the uplift and incision rates and the terraces to the east of the Cendere Bridge are taken as reference, the proportional effect was 25% tectonic and 75% climate change for the formation of terraces in the Adıyaman Basin.

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Author contribution: Conceptualization, Methodology, Funding acquisition, Visualization, Investigation, Writing- Original draft preparation, Project administration and Resources made by M. S. Data curation, Investigation, Writing-Original draft preparation and Resources made by Z. K. Conceptualization, Investigation, Methodology, Writing- Reviewing and Editing, Supervision and were done by H. Ç.

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