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CLIMATIC AND TECTONIC EFFECTS ON TERRACE FORMATION DURING THE LATE QUATERNARY IN THE UPPER YEŞILIRMAK VALLEY, NORTHERN TURKEY

Abstract: Altin T.B., Altin B.N. & Öztürk M.Z., *Climatic and tectonic effects on terrace formation during the late quaternary in the Upper Yeşilirmak Valley, northern Turkey. (IT ISSN 0391-9838, 2017).*

This study was carried out in the upper course of the Yeşilırmak River, which is one of the biggest rivers reaching the Black Sea, northern Turkey. We distinguished two fluvial terraces and dated them using OSL technique. T2 is the young terrace and situated at ~11 m above the actual river (at 620 m asl). T1 is the youngest and situated at ~5-6 m above the actual river (at 605 m asl). From the lower dated terrace (T1) was dated 6735 ka, 5277 ka and 4226 ka, respectively. From the higher dated terrace (T2) was dated 24,139 ka, 22,008 ka, 12,694 ka and 11,307 ka, respectively. While the higher terrace aggraded during three important cold periods (Heinrich 2 event (H2), the Last Glacial Maximum (LGM) and the Younger Dries (YD), the lower terrace (the present floodplain) aggraded during the Holocene Climatic Optimum (HCO). The river incised during transition from the LGM to Holocene transition and after the HCO. the Yeşilırmak has incised its valley ~11 m during the last 24 ka. These results indicate an average incision rate of 1.25 mm/yr (1.25 m/ka).

Key Words: Climate Change; Terrace; Incision; Late Quaternary; Yeşilırmak River.

INTRODUCTION

Sediment yields of the Yeşilırmak River, located in northern Anatolia, are driven by tectonic movement of the North Anatolian Fault (NAF) and by climate (Hubert-Ferrari & *alii*, 2002; Kazancı & *alii*, 2015). Recent works tend to emphasize climate change superimposed on tectonically driving terrace development (Bridgland, 2008, 2014; Demir & *alii*, 2012). Fluvial terraces are the abandoned floodplains of streams and rivers, and consist of unconsolidated deposits with basal unconformities known as straths and bench-like tops known as treads (Ritter & alii, 2002). Fill terraces are formed by valley aggradation and subsequent entrenchment into alluvial fills and reflect the adjustment of rivers to climatic perturbations or the lowering of base-level, the ultimate level of fluvial erosion (Jochems, 2013). In general, depositional terraces have been thought to reflect aggradation events controlled by climate or base-level change, whereas erosional terraces have been considered tectonically-controlled features (Bull, 1990). Staircase chronologies enabled the development of conceptual terrace development models, which uncover a close link between distinct fluvial processes and specific environmental (climatic) conditions (Stange, 2014). There are only a limited number of Holocene studies of fluvial development of the Yeşilırmak valley, especially its upper course (e.g., Gürbüz & *alii*, 2015; Huber-Ferrari & *alii*, 2002; Gürbüz & *alii*, 2013) and no studies on the fluvial terraces. However, there are studies of terrace formation and fluvial geomorphology related to the Kızılırmak River, which is located to the south of the Yeşilırmak and is the longest river within the borders of Turkey (Doğan & *alii*, 2009; Doğan, 2011; Görendağlı, 2011; Çiner & *alii*, 2015). Furthermore, Hubert-Ferrari & *alii* (2002) have addressed the question of determining slip rates of the NAF over various time periods using offset geological and geomorphological markers in the central section of the Yeşilırmak Basin. Erturaç & Tüysüz (2012) established the architecture of the Neogene-Quaternary basins developed along the Ezinepazar-Sungurlu Fault, which is a major offshoot of the dextral NAF zone, in the middle part of the Yeşilırmak Basin. Bozkurt & Koçyiğit (1996) documented the detailed stratigraphy and neotectonic structures of the Kazova basin, located in the upper section of the Yeşilırmak Basin,

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considering its kinematic significance, and they concluded that the basin is an active negative flower structure along the Almus fault Zone, which is a splay fault system of the NAF zone in the upper section.

The present study is the first report of the evolution of the drainage in the upper course of the Yeşilırmak and thus significantly advances our knowledge of Pleistocene-Holocene events in this scarcely studied geographic area. The aim of this study is to present the interaction between climatic changes and tectonic activity that might have impacted on the terrace formation in the upper course of this basin during the Late Quaternary.

GEOGRAPHIC AND GEOLOGIC SETTINGS

The study area includes the upper course of the Yeşilırmak Basin, which is in the southern part of the Middle Karadeniz Section. This area is located between Tokat Province and Almus Dam and covers an area of approximately 295 km². The lowest point of the study area lies at 600 m above sea level (asl). The highest mountain peaks are at 1780 m and 1600 m asl in southern and northern margins of the area, respectively. Thus, the relief difference between the floor of the Yeşilırmak valley and its southern and northern mountain fronts are 1163 m and 1082 m, respectively (fig. 1). The study area is located in an active tectonic zone and generally consists of the valleys that have subsided because of faulting. The basement of the study area is represented by the Tokat Massif, which is a regionally metamorphosed tectonic feature situated in the south-central Pontides (Yılmaz & *alii*, 1997a).The Tokat metamorphics belong to the Eastern Pontides Orogenic Belt in northern Turkey, which is commonly divided into the western, central and eastern Pontides (Yılmaz & *alii*, 1997a, b; Yılmaz & Yılmaz, 2004). The presence of pre-Liassic ophiolites has been suggested in the Tokat Massif and along the North Anatolian ophiolite Belt (Koçyiğit, 1991, Seymen, 1991, 1993; Yılmaz & *alii*, 1997a, b). This area is situated within the North Anatolian Fault Zone (NAFZ) with respect to tectonic setting

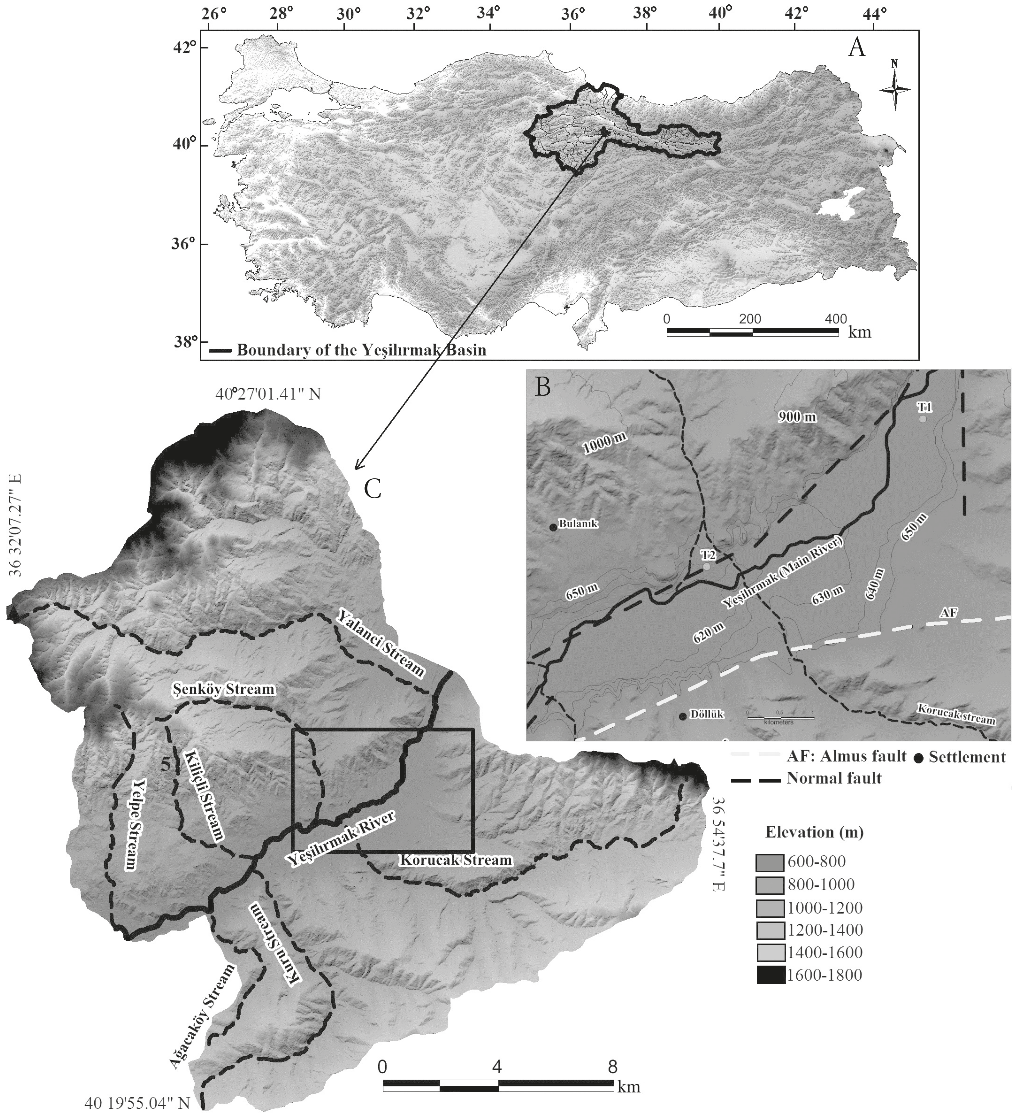

FIG. 1 - A) Location of the study area. B) location of dated terraces (T1, T2). C) Digital Elevation Model (DEM) of the study area.

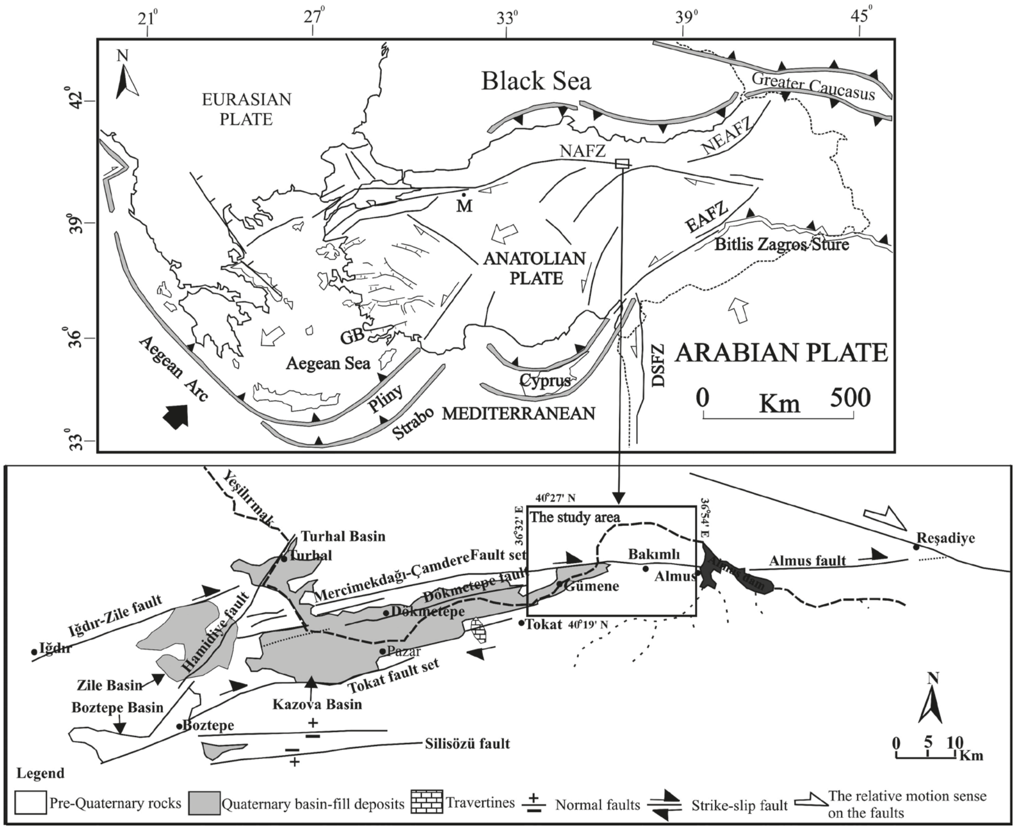

FIG. 2 - Simplified neotectonic map showing some major neotectonic structures of Turkey and continental ex trusion of the Anatolian block away from the Arabia-Eurasia collision zone (a) (modified from Koçyiğit, 1989). (b) the map showing Almus Fault Zone (after Koçyiğit and Bozkurt, 1991; Bozkurt and Koçyiğit, 1995).

(fig. 2a, b). This fault zone was mapped by Bozkurt & Koçyiğit (1996) and is known as the Almus Fault Zone (AFZ). The Almus Fault is approximately 160 km long (Bozkurt & Koçyiğit, 1995). Tectonic units evolved in relation to NAFZ affected formation of the drainage network and its evolution. The Yeşilırmak River has shown consistent lateral migration, causing the formation of many terrace systems and alluvial fans. The aforementioned geologic and tectonic features have affected the morphology of the study area. Tectonic and geomorphologic markers employed in the study area include river valleys, river terraces and alluvial fans. Numerous alluvial fans, young lower terraces and older higher terraces are present in the Yelişırmak valley.

MATERIALS AND METHODS

To evaluate tectonic and climatic processes, we prepared a detailed geomorphological map. The map is based on the Neogene and Quaternary erosion cycles in Turkey, which were determined by investigating the erosional surfaces and their correlated sediments (Erol, 1983), and were derived from 1:25,000 scale topographic maps. According to this map, the denudational evolution of the Anatolian Peninsula has been a continuous process controlled by Neotectonic phases, climatic changes and sea-level oscillations since the Late Oligocene (Erol, 1991; Fairbridge & *alii*, 1997).

OSL dating method

In addition to the measurements of the amount of U, Th and K obtained from ICP-MS analyses of the samples collected from stream terraces, calcimetrically measured total $CaCO_3$ amounts and the results of water content analysis on the waterlogged samples were used to increase the reliability of the data in OSL dating. Since the OSL ages are calculated as the ratio of total absorbed radiation dose in the samples to the amount of radiation dose, the calculation of the dose ratio obtained from the measurement of these radioactive elements (U, Th, and K) that originate from cosmic rays and belong to the medium is of great importance. Again, the measurements of the ratio of carbonate that affects the BETA dose rate and has a significant impact on the dating of ages as high or low are very important in this respect. To assure the reliability of data, the analyses were repeated average seven times (n) for each of the 11 samples. Since the sample depth is important in terms of cosmic ray intrusion, the depths have been measured accurately and they range between 50 cm and 365 cm. In the samples, the average of calcium carbonate content is 6.8% and this result is due to excess calcium carbonate content in two of the samples; otherwise the calcium carbonate content is less than 4% in many of the samples. According to the dating data obtained, the error uncertainty factor (±) or the margin of error is generally 10%; however, it is higher in some of the samples (since the margin of error in OSL dating studies ranges between 5-12%, the values obtained are at reasonable levels).

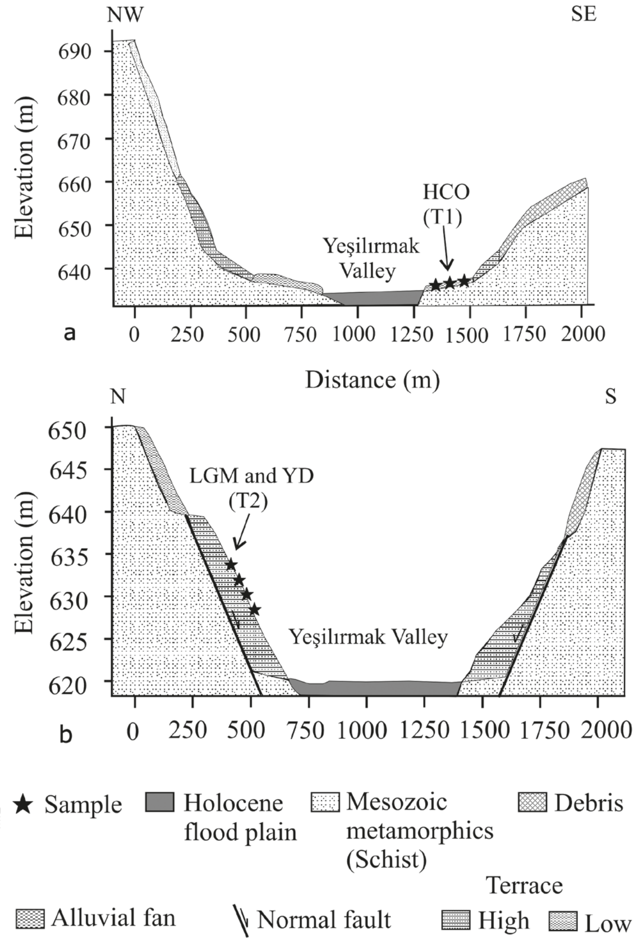

FIG. 3 - Schematic transverse profile showing the relations of terraces T1 and T2 (LGM: Last Glacial maximum, YD: younger Dryas, HCO: Holocene climatic optimum). Location of cross-section is seen in Fig. 9.

For OSL dating, seven fluvial sand samples were collected at different levels of two terraces (fig. 3). Terraces 1 and 2 have thicknesses 7 and 4 m, respectively. Samples were collected with black metal tubes that were 50 cm long and 8 cm in diameter. Luminescence analysis of the samples was conducted at the Luminescence Research and Archeometry Laboratory of Isik University, Turkey. T2 is the young terrace and situated at ~11 m above the actual river (at 620 m). T1 is the youngest and situated at ~5-6 m above the actual river. In this scheme, strath elevation of each terrace level is taken into account to represent the elevation above the actual river. In addition, we used the exact sampling elevations from where the OSL ages and uplift rates were calculated relative to the actual river.

RESULTS

Our OSL results show that the upper and lower dated terraces aggraded in cold and warm periods, respectively (tab. 1). The upper terrace aggraded during three important cold periods: the Heinrich 2 event (H2), the Late Glacial Maximum (LGM) and Younger Dryas (YD). The upper terrace (T2) consists of poorly sorted to well-sorted silt, sand and gravel (fig. 4) that are associated with cold periods during the LGM and YD. The higher terraces are deeply dissected and are 4 m thick, and located on the southern and northern block of Almus Fault. These findings differ from ours and contrast with the terrace uplift rates obtained from the Yeşilırmak terraces. Namely, in the study area (the Yeşilırmak valley), both the high and low elevation terraces were deposited during cold and warm periods. Sediments transported by meltwater streams draining nearby highland areas accumulated in the valley during cold periods. During warm periods, increased rainfall could quickly lead to local flooding and runoff, causing terrace accumulation.

The lower terrace (T1) contains muddy gravel levels and levels where gravel is intercalated with boulders and includes abandoned channel deposits that underlie the

TABLE 1 - OSL, equivalent doses, dose rates and parameters used for dose rate estimation for samples.

Lab	Depth	Age	Dose	Dose rate	Carbonate	U	Th	K	n
Code	(cm)	(ka)	De (Gy)	(Gy/ka)	(%)	(ppm)	(ppm)	(%)	
T1-1	250	6,735±0,689	7,586±0,744	1,13±0,00	6,68	0,5	2,1	0,14	11
T1-2	110	5,277±0,472	5,750±0,478	1,09±0,04	3,82	0,5	3,7	0,24	7
T1-3	50	4,226±0,718	5,119±0,849	1,21±0,04	21,1	0,6	2,3	0,13	7
T2-1	365	24,139±2,305	9,938±0,784	0,41±0,02	1,13	0,5	2,9	0,16	6
T2-2	340	22,008±2,274	8,377±0,698	0,38±0,02	3,5	0,5	3	0,19	6
T2-3	270	12,694±1,258	5,580±0,426	0,44±0,03	1,05	0,5	2,5	0,18	8
T2-4	230	11,307±1,209	5,357±0,476	0,47±0,03	1,95	0,5	2,7	0,2	7

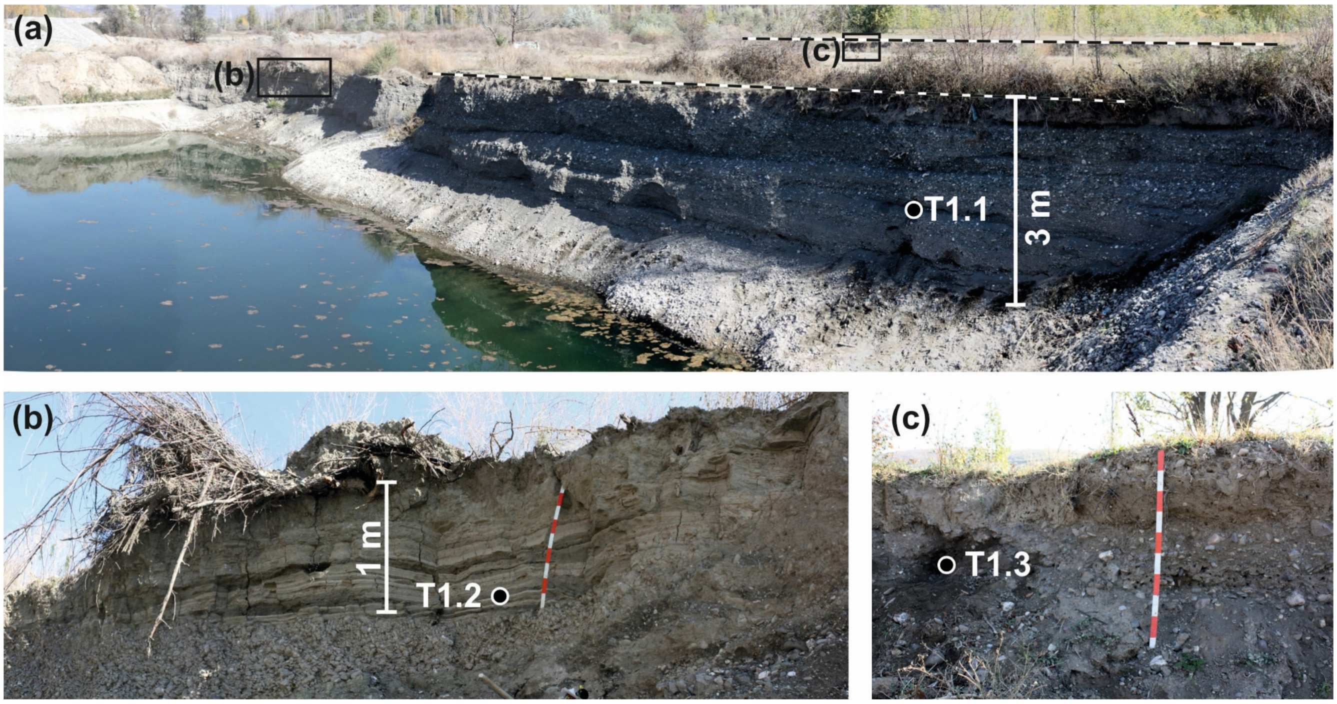

FIG. 4 - Sampling point of terrace 2.

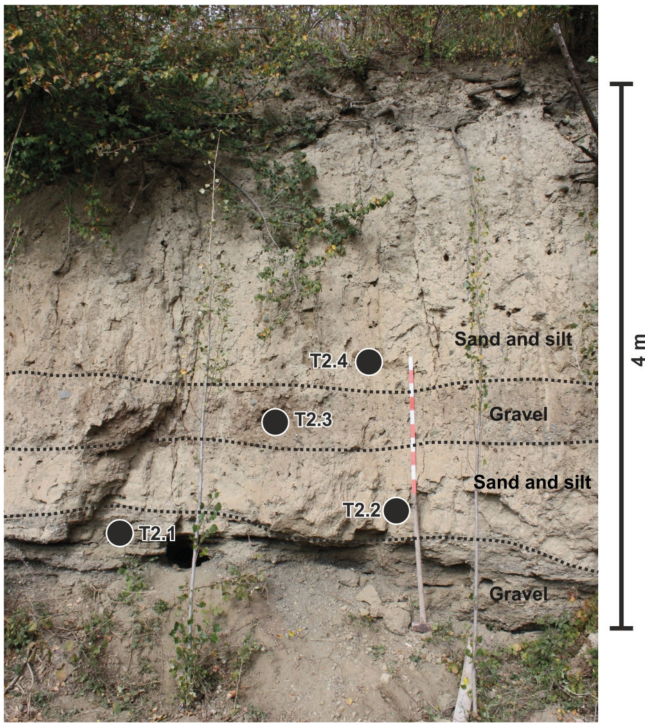

FIG. 5 - Sampling point of terrace 1.

modern floodplain (fig. 5a, b). The deposits are Holocene in age and are generally characterized as abandoned channel floor, which are resistant to lateral erosion. The deposits reflect climatic changes and probably an enhanced fluvial regime in the Yeşilırmak River valley during warm and wet periods at 6700, 5200 and 4200 cal. yr BC. In addition, T1 terrace is the lowest and youngest fluvial deposit dated in this study and it is only 5 m higher than the average elevation of the recent flood plain (630 m) of the Yeşilırmak River. Three samples obtained from the T1 provided the youngest OSL ages. The ages range between 6,735 ± 0,689 years and 4,226 ± 0,718 years. The difference between the samples collected from 2 meters and 50 cm is in line with the stratigraphy. These ages that correspond to a depositional phase between the beginning of Holocene (post Younger Dryas) and the Middle Holocene (MIS1) are in fact the period between Preboreal-Atlantic according to Holocene chronology and it is a period when a transition from cold conditions at the beginning of Holocene toward more temperate and humid conditions occurred. This Late Quaternary terrace has resulted from climatic change rather than surface uplift. Minor but abrupt water level fluctuations (peak discharges) in the valleys can be identified over the past 6000 years.

Our data shows that the Yeşilırmak River has incised its valley by 11 m during the last 24 ka. Terraces at 2 m and 13 m above the current river yield ages ranging from ca. 4200 to 24 ka, corresponding to an average incision rate of 1.25 mm/yr (1.25 m/ka) since 24 ka (fig. 6).

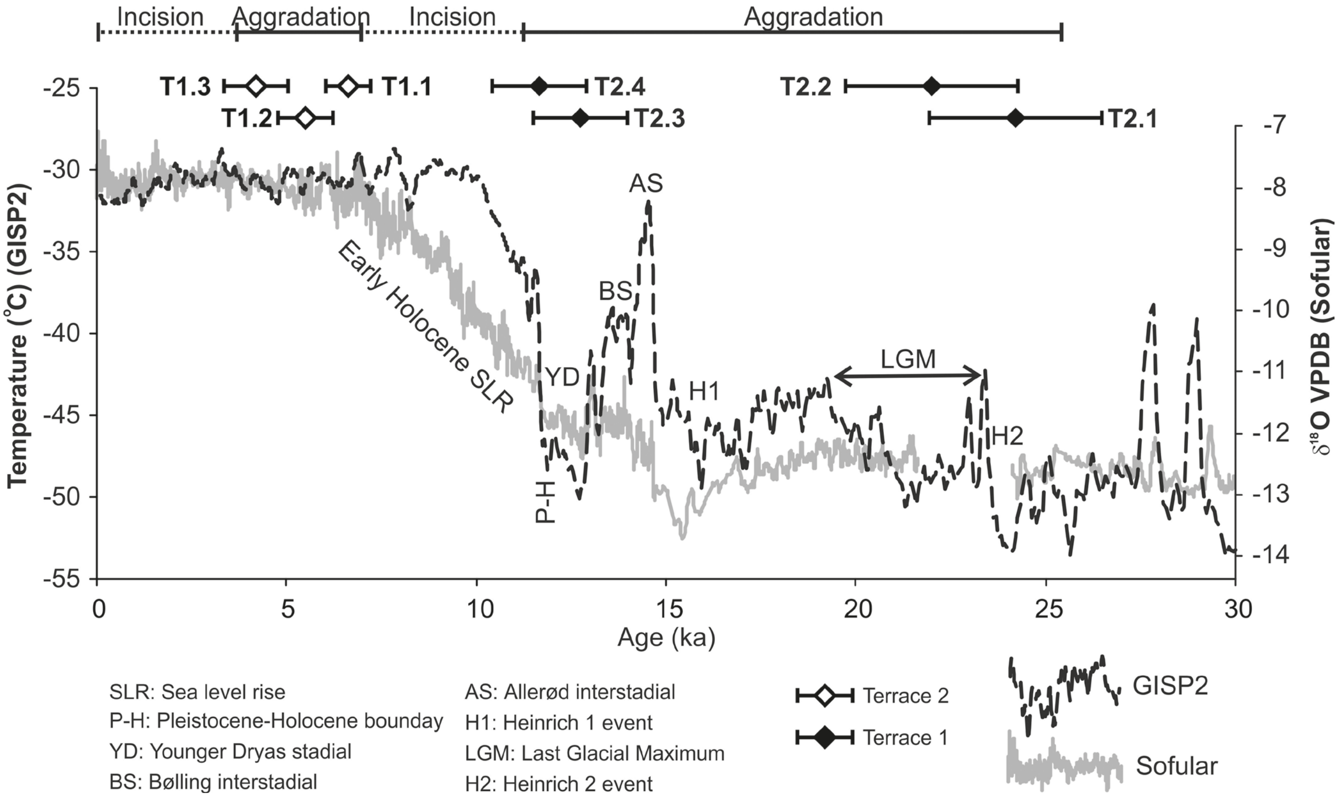

FIG. 6 - Air temperatures from the GISP 2 ice core from Greenland (Alley, 2000), δ18O record of stalagmites from Sofular Cave (Fleitmann & alii, 2009) and OSL ages. Periods of aggradation and incision.

DISCUSSION

OSL ages and climatic controls on terraces

Aggradational river terraces result from the combined effect of progressive surface uplift and the cyclic climatic changes that have triggered the fluvial activity (Bridgland, 2000; Maddy & *alii*, 2001, 2005; Westaway & *alii* 2006b; Antoine & *alii*, 2007; Bridgland & Westaway, 2008; Vandenberghe, 2008; Gibbard & Lewin, 2009). Temperature and precipitation fluctuations are the key forcing factor in controlling fluvial processes (Vandenberghe, 2003; Bridgland & Westaway, 2008). In particular, the intensity of precipitation and its seasonal distribution play major roles in determining the processes of erosion and deposition in rivers (Vandenberghe, 2003; Seyrek & *alii*, 2008). Therefore, cold and warm phases are equal to erosional as well as depositional activity and quiescence, respectively (Gibbard & Lewin, 2009).

According to Türkecan & *alii* (2004), this incision might have occurred during the Late Glacial based on the assumption that pleniglacial conditions were cold and dry, so an increase in precipitation occurred during the Late glacial. The results of Doğan (2010) indicate that the main incision phase occurred during the LGM (approximately 19-21 ka) as a response to climatic change. Kıyak & Erturaç (2008) examined terraces located at various elevations on the gorges of the two major tributaries of Yeşilırmak River (in the western part of the study area) using OSL dates. Their results indicate that formation of the oldest terrace in the west started at the beginning of the Late Glacial period (109.5±7.4 ka) and accumulated at least ~40 metres before 34.7±2.5 ka ago. The eastern terrace started to develop after an apparent delay (at around 47.0±2.2 ka), but then has a similar depositional history, which ended around 35.2±6.9 ka ago (Kıyak & Erturac 2008). These terraces were controlled by tectonic activities of the Ezinepazar-Sungurlu Fault which is a major off shoot of the dextral North Anatolian Fault Zone within the last 50 ka (Kıyak & Erturac 2008; Erturaç & Tüysüz, 2012). The relation between fluvial terraces and climate change in Anatolia has been investigated by many researchers (Kuzucuoğlu & *alii*, 2004; Demir & *alii*, 2004, 2007, 2008, 2009; Westaway, 2006a, b; Seyrek & *alii*, 2008; Maddy & *alii*, 2008; Doğan, 2010, 2011; Kuzucuoğlu, 2013). Doğan (2010, 2011) suggested that the main incision and aggradations occurred in cold (especially glacial maxima) and warm periods (including cold-warm climate transitions), respectively. However, Demir & *alii* (2004, 2007, 2008, 2009), Westaway & *alii* (2006a), Seyrek & *alii* (2008) and Kuzucuoğlu (2013) have suggested that fluvial deposits aggraded during cold periods. Although a number of other studies have also demonstrated correlations between MIS stages and terrace formation times in other regions (e.g., Benedetti & *alii*, 2000; Pazzaglia &

Brandon, 2001; Schildgen & *alii*, 2012a), the ages from the Yeşilırmak valley show a variable relationship with glacial and interglacial stages. In western Turkey, individual gravel terraces have been attributed to particular climate cycles between MIS 48 and 28 (Westaway & *alii*, 2003, 2006a, b; Maddy & *alii*, 2005, 2008, 2012). In Sinop Peninsula situated within northern Turkey, OSL ages suggest terrace formation episodes during interglacial periods at ca 125, 190, 400 and 570 ka, corresponding to marine isotopic stages (MIS) 5e, 7a, 11 and 15 (Yıldırım & *alii*, 2013a). In the Ceyhan River situated within southern Turkey, Seyrek & *alii* (2008) determined a terrace assigned to MIS 10. In the region around the NE corner of the Mediterranean, terrace evidence from rivers flowing through Turkey and Syria: from NW to SE, these are the Ceyhan (Seyrek & *alii*, 2008), Orontes (Bridgland & *alii*, 2012) and Kebir (Bridgland & *alii*, 2008), all of which record more rapid uplift than is typical, resulting in sequences that do not extend back beyond the Middle Pleistocene (Bridgland & Westaway, 2014). These rivers traverse the boundary zone between the Turkish, African and Arabian plates (e.g., Duman & Emre, 2013). According to Bridgland & Westaway (2014), the local effects of active faults accommodating the plate motions are superimposed onto the more general effect of erosional isostasy in driving the uplift.

The difference in the timing of terrace formation between the central part of the plateau and its northern side suggests that variations in sediment transport or release resulting from glacial-interglacial cycles are not the only factor that controls the change between lateral and vertical river incision along the Yeşilırmak valley. Rather, the Yeşilırmak Basin might experience vertical uplift associated with the Almus Fault (AF) that vary on the time scale of individual terrace formation (Hubert-Ferrari & *alii*, 2002; Şengör & *alii*, 2005; Yıldırım & *alii*, 2013b; Gürbüz & *alii*, 2015), or other minor climate cycles could influence the formation of terraces in the Black Sea region (Yıldırım & *alii*, 2013b). However, there are no studies related to rate estimates allowing us to compare this possibility further in the study area.

Doğan (2005) distinguished three cycles related to the formation of the terraces in the Upper Tigris valley (Eastern Anatolia): Pleistocene-Early Holocene, Early Chalcolithic (5500-4000 BC) and Early Bronze Age 1 (2800-2650 BC). More than three terraces have been identified in the Kızılırmak River (Central Anatolia) (Doğan, 2011).

Differential uplift among the northern, southern, western margins and the study area on fluvial terrace formation

Fluvial incision or aggradation may result from tectonic and climate change or both of these forcing mechanism. Tectonic uplift is a common cause of terrace formation in tectonically active regions (Brunnacker & *alii*, 1982; Li & *alii*, 1996; Wang & *alii*, 2009). However, climatic change may be the most direct cause of terrace formation (Fisk, 1951; Chatters & Hoover, 1992) because hydrological dynamic parameters that dominate riverbed sediment aggradation and transportation (e.g., flux and flow velocity) are directly related to climatic conditions (Bull, 1991).

Our findings implies that incision rates of the Yeşilırmak are more rapid than the southern margin (Doğan, 2011; Aydar & *alii*, 2012; Çiner & *alii*, 2015) of the study area due to the greater effects of AF tectonic movement during the end of the Quaternary than the Tuzgölü Fault located in the Central Anatolia Province (CAP). Çiner & *alii* (2015) dated the Kızılırmak terraces by obtaining cosmogenic burial age estimates. Their results suggest mean incision rates of 0.051 mm/yr mean incision rates over the last 1.9 Ma. They suggested that uplift rate of the CAP is up to 5-10 times slower than southern and northern margins of the CAP. Aydar & *alii* (2012) have similar findings. Their results indicate that the incision rate was 0.12 mm/yr between 5 Ma and 2.5 Ma, and that in the last 2.5 Ma, it slowed down to 0.04 mm/yr. within the CAP. Doğan (2011) also calculated uplift rates for the Kızılırmak based on relative stratigraphy of fifteen terrace sequences and four basalt $^{40}Ar/^{39}Ar$ ages. According to his findings, vertical incision rates are 0.08 mm/yr averaged over the last 2 Ma. Schildgen & *alii* (2012a) calculated average uplift rates of 0.25-0.37 mm/yr between 8 and 5.45 Ma, and 0.72-0.74 mm/yr after 1.66 to 1.62 Ma. in the Mut Basin located within southern Turkey. They also calculated Göksu River terraces in the Mut Basin to show average incision rates of 0.52-0.67 mm/yr between 25 and 130 ka (Schidgen & *alii*, 2012b). Similarly, Cosentino & *alii* (2012) calculated uplift rates for the Mut-Ermenek Basin and average uplift rate of 0.24-0.25 mm/yr since 8Ma. These studies also indicate that incision rates of the Yeşilırmak are more rapid than the southern margin of the CAP. In the Ceyhan River, Seyrek & *alii* (2008) determined uplift rates of up to ~0.4 mm/a, from the fluvial terraces. Despite an initial tectonic trigger, they suggested that the resulting uplift has been driven primarily by erosion and is thus a consequence of the effect of climate on erosion rates. In western Turkey, terraces of the Gediz River are considered to represent sedimentation-incision cycles which span the period ~1.67-1.2 Ma, with an incision rate of 0.16mm/a (Maddy & *alii*, 2007). In the Sinop Peninsula, Yıldırım & *alii* (2013a) calculate average vertical displacement rates (without eustatic correction) of 0.02 and 0.18 mm/a, with intermittent faster rates of up to 0.26 mm/a. Yıldırım & *alii* (2013b) calculated river-incision rates based on an individual fluvial strath terrace. According to their findings, the individual terraces yield incision rates ranging from 0.2 to 0.3 mm/a in the northern margin of the CAP, which coincides with the central Pontides between the NAF and the Black Sea. Yıldırım & *alii* (2013a, b)'s findings support our findings related to uplift rate depending on NAF.

Terraces in tectonically active mountains and uplands record both tectonic uplift and rhythmic climatic variations (Starkel, 2003). Upon reaching the Black Sea, the Yeşilırmak forms a delta plain and its paleo-levels (marine terraces) are elevated at 8-10 m, 25-30 m, 35-50 and 80-90 m above sea level (Erkal, 1993). The limited extent of the marine terraces at different levels was effected by the Quaternary tectonism and the Late Quaternary sea-level changes (Bilgin, 1963). Indeed, in T2, the OSL age obtained from quartz in the sand collected just below the terrace surface is 11,307 ± 1,209 years. At this level, the

TABLE 2 - Uplift rate of southern and northern margins.

The Study Area	Uplift rate	Age	Dating Method	References
Kızılırmak River (Central Anatolia)	0.12 mm/yr	2 Ma	$^{40}Ar/^{39}Ar$	Doğan, 2011
Kızılırmak River (Central Anatolia)	0.051 mm/yr	1.9 Ma	^{10}Be and ^{26}Al $^{40}Ar/^{39}Ar$ and $^{206}Pb/^{238}U$	Çiner et al., 2015
Southern Kızılırmak (Central Anatolia)	0.12 mm/yr	5 Ma	40Ar/39Ar	Aydar et al., 2012
Mut Basin (Southern Margin)	0.6-0.7 mm/yr	1.6 Ma	^{10}Be and ^{26}Al	Schildgen et al., 2012a
Göksu River (Southern Margin)	0.52-0.67 mm/yr	25-130 ka	CA-TIMS U-Pb zircon	Schildgen et al., 2012b
Mut-Ermenek Basin (Southern Margina)	0.24-0.25 mm/yr	8 Ma	$\delta^{18}O$ and $\delta^{13}C$	Cosentino et al., 2012
Ceyhan River -Mt. Amanos (Southern Margin)	0.15-0.4 mm/yr	3.7 Ma	$^{40}Ar/^{39}Ar$	Seyrek et al., 2008
Orontes River (Sothern Margin)	0.2-0.4 mm/yr	0.9-1.2 Ma	Uranium-Series dating	Bridgland et al., 2012
Northen Sinop Peninsula (Northen Margin)	0.2-0.3 mm/yr	0.35 Ma	OSL dating	Yıldırım et al., 2013a
Southern Sinop Peninsula (Northen Margin	0.22-0.11 mm/yr	400-190 ka	OSL dating	Yıldırım et al., 2013a
Gökırmak River (Kızılırmak-Northen Margin)	0.2-0.3 mm/yr	0.35 Ma	^{10}Be, ^{21}Ne and ^{36}Cl	Yıldırım et al., 2013 b

OSL age obtained from the layer that is 1.3 meters lower is 24,139 ± 2,305 years. These results indicate that the deposition age of quartz sand in the river bed in this locality is between 24-11 ka. However, there is an erosion phase between the sands at the bottom (between 270-230 cm) and the sands on top (365 cm-340 cm). Indeed, there is no deposition phase that belongs to a period of 10-11 ka between them. According to this, it corresponds to just before the last glacial maximum (Marine Isotope Stages-MIS), in other words, it corresponds to the MIS2 period when cold and dry conditions were dominating and the sea level was 100 meters lower than it is today (Shumilovskikh & *alii*, 2014); therefore, the river erosion activities were strong. In addition, stream capture is a geomorphic phenomenon that may trigger and/or accelerate incision due to additional discharge obtained from captured streams or water bodies (Stokes & *alii*, 2002; Yıldırım & *alii*, 2013b). The Yesilirmak flows south of the NAF toward the NE, and then defines a right-lateral offset a few kilometers along the NAF (Barka, 1984).

The uplift rates from previous studies mentioned above imply that tectonic activities increase from the southern to northern margins of Turkey (tab. 2, fig. 7). From the fluvial evidence, estimated amounts of regional uplift since the Miocene are typically c. 400 m in western Turkey and in the area of the border with Syria, however, they increase northward and eastward to c. 1 km or more in northeastern Turkey on this time-scale, reflecting the regional variations in mean altitude of the land surface (Demir & *alii*, 2004). This is consistent with the general southward tilt of the northern Arabian platform, indicative of a southward decrease in uplift (Demir & *alii*, 2012; Bridgland & *alii*, 2014). Estimated typical uplift rates during the Middle and Late Pleistocene have been *c.* 0.1 mm/a in the Arabian Platform and *c.* 0.2-0.3 mm/a in western and northern Turkey (Demir & *alii*, 2004).

Geomorphology

Tectonic mobility actively determined the high topography and denudational surfaces up until the end of the Miocene, which continued during the Pliocene and determined the flow directions of the main fluvial courses. The resultant streams incised the previous generation of landforms, thus causing the development of the nested fluvial topographic units. Faulted blocks parallel to the Yeşilırmak River affected slope development and formed sliding surfaces depending on the underlying rock units. The activity of the North Anatolian fault zone is the major force of these movements (Bilgehan & Kılıç, 2007). In the middle and lower parts of the Yeşilırmak River basin, streams have valley depths of ~1 km on both sides of the North Anatolian

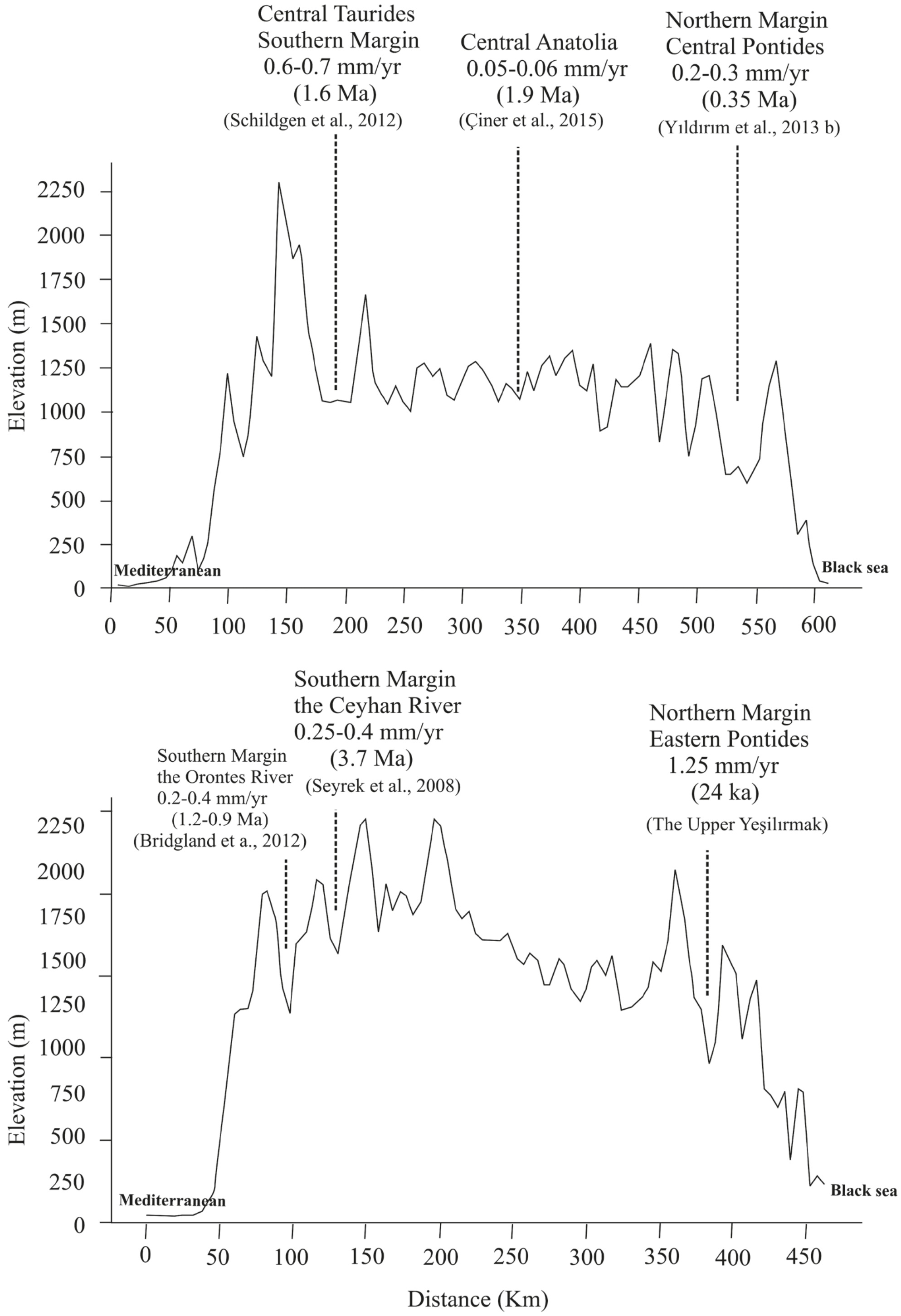

Fig. 7 - Cross-sections from southern margin and northern margin. See Fig. 1a for the cross-sections

fault zone around the Niksar and Taşova-Erbaa pull-apart basins and represent a high relief against the low relief of the upper part of the drainage basin (Gürbüz & *alii*, 2015). They suggest that the high incision rates for these areas are also controlled by vertical block tectonics of the NAF, but the primary effect should be caused by sea level changes in the Black Sea during the Quaternary period.

The alluvial fans that developed at the mouths of streams joining the Yeşilırmak River also brought about changes both in the course of the river as well as the Yeşilırmak valley. A similar study was carried out in Morocco (Stokes & Mather, 2015). They suggest that morphologically, these fan-generating catchments have higher relief, longer lengths, lower gradients, and larger

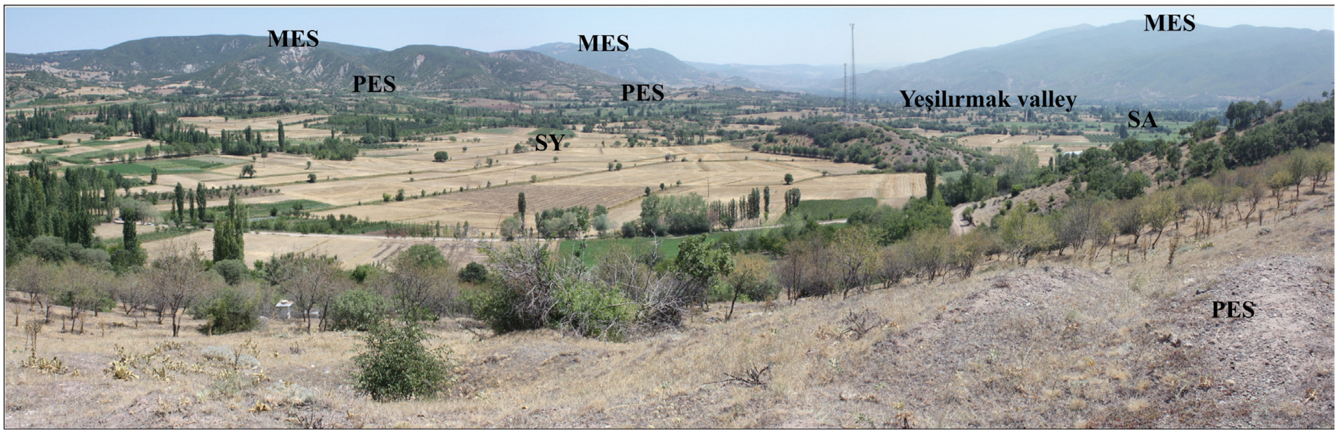

FIG. 8 - View looking towards the east from the village of Bula. The Pliocene erosional surfaces (PES) that penetrate the Miocene surface are in the background. The conical hills that rise above the Upper Miocene surfaces (MES) are deeply dissected. In the foreground, higher (SY) and lower (SA) terraces of the Yeşilırmak River are present.

areas than nonfan-generating catchments with clear lower and upper threshold values. Faults extending beyond the valley and ophiolite debris transported by the streams caused the development of these fans. These fans include mostly thin bedded silt, clay deposits and coarse-gravels. Similarly, Bozkurt & Koçyiğit (1996) identified similar alluvial fans in the Kazova Basin located in the AFZ and western part of the study area. They suggest that the marginal coarse-grained sediments of the alluvial fans indicate rapid uplift of the mountains, erosion and rapid sedimentation. In the study area, alluvial fans that unconformably overlap with older alluvial fans and the high terraces imply that subsidence has occurred in the Yeşilırmak valley and its streams, and these fans located on the T2 terrace aligned parallel to the fault-controlled northern block. This indicates that tectonically active and quiet periods can be distinguished in the formation of the T2. Today, a stacking pattern exists in the terraces and alluvial fans above the actual base of the basin, and the old and the new sand and gravel banks imply both climate oscillations and fluvial changes in the stream beds. Alluvial fans have two steps and provide evidence for vertical downward movement of the land. This indicates that development of the basin and sub-basins continued during the end of the Pleistocene.

Erol (1983) suggests that, several step-like terraces developed under the influence of tectonic movement and fluvial activity by the end of the Early Pleistocene. Hubert-Ferrari *& alii* (2002) proposed that the Yeşilırmak might have deposited a large amount of fluvial sediments along its courses before the NAF propagation took place at 5-8.5 Ma. Prior to that time, the Yeşilırmak Basin has internal drainage network (Keçer & Tüfekçi, 1986). Tectonic movements caused uplift of the basin and eventually its dissection during the Upper Miocene (fig. 8). Thus, a continental basin was formed in the northern part of the study due to opening of the NAF. This new tectonically controlled basin was incised by streams during the Pliocene. The landscape included inclined pediment surfaces, conical hills (inselbergs and bornhards), continental sediments with vertebrate fossils, and evaporite deposits (playas) at the foot of the hillslopes (Erol, 1980).

The Yeşilırmak River must have been exposed to any changes in the elevation of its outlet to the Black Sea at approximately the same period of time (Erkal, 1993). Consequently, these four terraces might have been formed and Erol system (1980, 1983, 1991) supported this formation. At the beginning of the Pliocene, a new subhumid-subtropical phase began and fluvial landform generation dominated the highlands (Erol, 1983). During this period, tectonic effects gradually decreased and fluvial activity increased due to climatic changes. Large, deep river valleys developed and penetrated inland to the north and south of the study area by headward erosion. With the exception of the modern channel of the Yeşilırmak River, the dominance of gravel, silt, clay and sand in the old terrace deposits and gravel pits in its floodplain and agricultural areas indicates that stream flow is not constant and that temporary marshy are characteristic, as is the formation of braided drainage channels. These formations can be seen north of the village of Çöreğibüyük among Karakaya, Akbelen and Gözova settlements. The talus transported from the mountain areas by floods and sheet floods lies unconformably on the terraces and alluvial fans (Fig. 9). This talus forms glacis-type slopes that connect the high erosional and depositional surfaces at the basin edges. Moreover, human interventions during ancient times have caused changes in stream flow (Altın, 2015).

CONCLUSIONS

In this study, although terraces dated are few, these terraces provide a basis for the determination of the regional tectonic frame work. Our OSL ages from flights of fluvial terraces in the upper course of the Yeşilırmak reveal incision induced by ongoing rock uplift for at least the last 24 ka in the study area. According to the present level of the Yeşilırmak the mean incision rate for this part of the plateau yielded 1.25 mm/yr (1.25 m/ka).

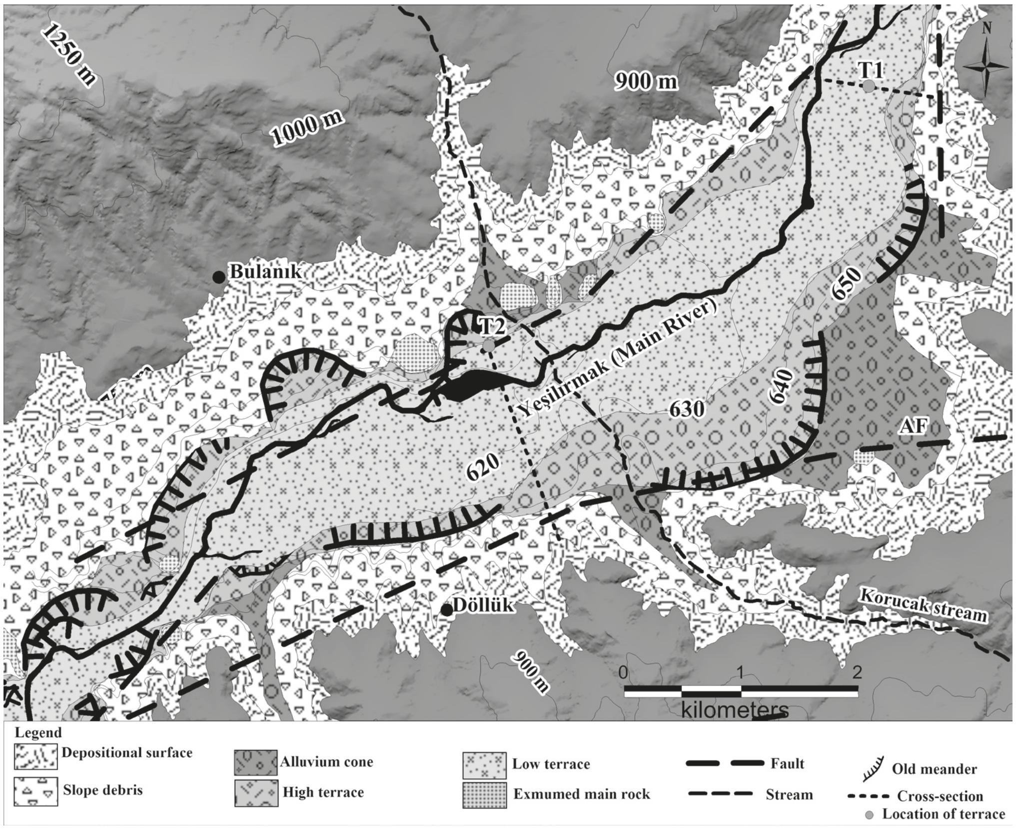

FIG. 9 - Geomorphological map of the study area. See fig. 1 for location.

Our mean denudation rate from a valley fill also yields 1.24-1.25 mm/yr, which is consistent with the mean rock uplift rate, indicating unsteady conditions depending on tectonic activity in the study area. This rate in the upper course of the Yeşilırmak has been considerably more rapid than southern and central regions of Turkey respectively, however, conform with northern margins of Turkey respectively, however, consistent with northern margins of Turkey. The spatial distribution of the strath terraces and their relationship with local faults affected by AF imply that development of the topography in this region was initiated by the onset of the present phase of plate motions in the Mid-Miocene, the resulting uplift has been driven primarily by erosion and is thus a consequence of the effect of tectonics on erosion rates in the study area. Given these factors, aggradation and incision of terraces is driven by the interactive forcing of both climatic changes and tectonic activity of the Almus Fault.

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