



Soil formation on a calcic chronosequence of Ancient Lake Konya in Central Anatolia, Turkey

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ABSTRACT

With the passage of time, different soils show a wide range of variation in their formation. The passage of time in soil formation affects both soil features and the rates of weathering. The aim of this research is to study and compare the pedogenic evolution of soils developed on the terraces of Ancient Lake Konya using weathering indices such as Chemical Index of Alteration (CIA), Chemical Index of Weathering (CIW), and Eu and Ce anomalies. The study will also take into account other features, such as the physical and chemical properties, the analytical characteristics and how soil formation is determined according to the passage of time. For this purpose, four representative profiles were dug at different levels. After the macro-morphological identifications were completed in all the profiles, the samples were then collected from the horizons and were analysed for their physical, chemical, mineralogical and geochemical properties.

Although the soils in the study field were formed in different terrace levels, no significant relationship between the age of the soil and the soil properties was found. The lone exception was the clay movement in profile 1, which resulted from the limitation in profile development caused by erosion. Moreover, this erosion was the result of an increasing slope from the low terrace to the high coastal terraces. Similar physical, chemical and mineralogical characteristics were determined in the profiles. Using geochemical characteristics, the determined weathering indexes and their anomalies showed a very limited variation between the profiles, which suggests that though they differ in terms of age, the profiles have similar weathering levels. The climatological factors continuing along the Holocene were not efficient enough to change the effect of the other soil formation factors in the last period of the Quaternary. Therefore, it was concluded that the main factors determining soil formation are climate and topography, both of which determine the leaching regime and the weathering rates.

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1. Introduction

With the passage of time, different soils show a wide range of variation in their formation. During early pedogenesis, the chemical composition of a soil will be highly controlled by the composition of the geological parent material, whereas the chemical composition of mature soils strongly reflects the effects of the weathering environment. With time, soil composition diverges progressively from that of the parent material, which is under the influence of pedogenic processes determined by vegetation, topography and, in particular, climate. For soil formation, the passage of time affects the features of the soils and the rates of weathering. However, even if the passage of time in the soil formation is the same, the soil morphology and the physico-chemical characteristics can vary because of the effects of other soil formation factors. The divergence might be manifested initially by a redistribution of

elements within the soil fabric, then between the profile horizons and then finally between the soils within the landscape (Jenkins and Jones, 1980).

Soil chronosequences are often used to demonstrate the relative degree of soil development under varying duration of soil formation given that other soil formation factors are similar. A soil chronosequence is a series of soils for which physical, biochemical and weathering characteristics vary primarily as a function of deposit age. Surficial deposits of a similar age share similar soil properties when other factors of the soil formation are held relatively constant (Jenny, 1941). The age of a soil formation determines the soil properties in different ways. For instance, the soil formation can change the physical, chemical and mineralogical compositions of soils, or it can form a number of different soil horizons. Over time, the soil formation and the mobilisation and redistribution of elements during weathering follow various pathways. Thus, different elements are affected differently by the various pedogenic processes; these processes include the dissolution of primary minerals, formation of secondary minerals, redox processes, transport

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of material, and ion exchange in soil–water–plant systems. The rate of soil changes varies substantially with respect to different properties. For example, the formation of redoximorphic features might occur within decades or even several years, while the formation of an argillic horizon normally takes thousands of years (Yaalon, 1971; Walker, 1989; Zhang and Gong, 2001).

Birkeland (1999) proposed that the elements released by weathering might or might not be redistributed down-slope as a function of the element's mobility under the constant or changing geochemical environments along the slope. The distribution of metal among soil components depends on the combination of several soil properties, including soil type, texture, pH, redox condition, organic matter content, and mineral composition (Nguyen-Trung et al., 1992). The determination of soil age and weathering rates is the basis for assessing soil development and quantitatively understanding the Quaternary environmental changes (Phillips, 1993; Schatzel et al., 1994).

There have been few studies conducted that combine a comprehensive soil chronosequence based on a well-dated parent rock with an adequate number of soil profiles of different ages in Turkey. By using a series of geochemical indicators and physico-chemical properties, such a study might add substantial information to the quantitative understanding of soil development models in our country.

Studies that investigate the weathering process of soils and sediments, morphological properties, pH, organic matter, lime content, soluble salt content, free Fe, particle size distribution, sand

content (Akgul, 1995) and geochemical properties such as weathering indices and trace elements, especially REE data in the form of chondrite-normalised plots, have been widely performed. The aim of this study is to investigate and better explain the local patterns of soil development in a soil chronosequence with respect to the soil forming factor time in a semi-arid environment with similar geological patterns and climate. The weathering rates and some geochemical features, along with other features such as the mineralogy and some analytical characteristics, are presented here to discuss their use in quantifying the maturity stages and durations of soil formation in the Holocene.

2. Materials and methods

2.1. Site description

In the damp phases of the Quaternary, a large lake was formed in the Konya Basin. The level of this lake decreased significantly as a result of the climate becoming dry 17,000 years ago. The lake dried to form the Konya plain. Around the lake, there are upper coastal terraces, main coastal terraces and lower coastal terraces from the Neogene period. In this study, the soils formed on these terraces were used. With this aim in mind, the terraces in the Çumra region, which compose a part of the Konya Plain, were chosen.

The Great Konya Basin in Konya Province, Turkey, is located in the Central Anatolian Plateau at latitude 37–38°N and longitude

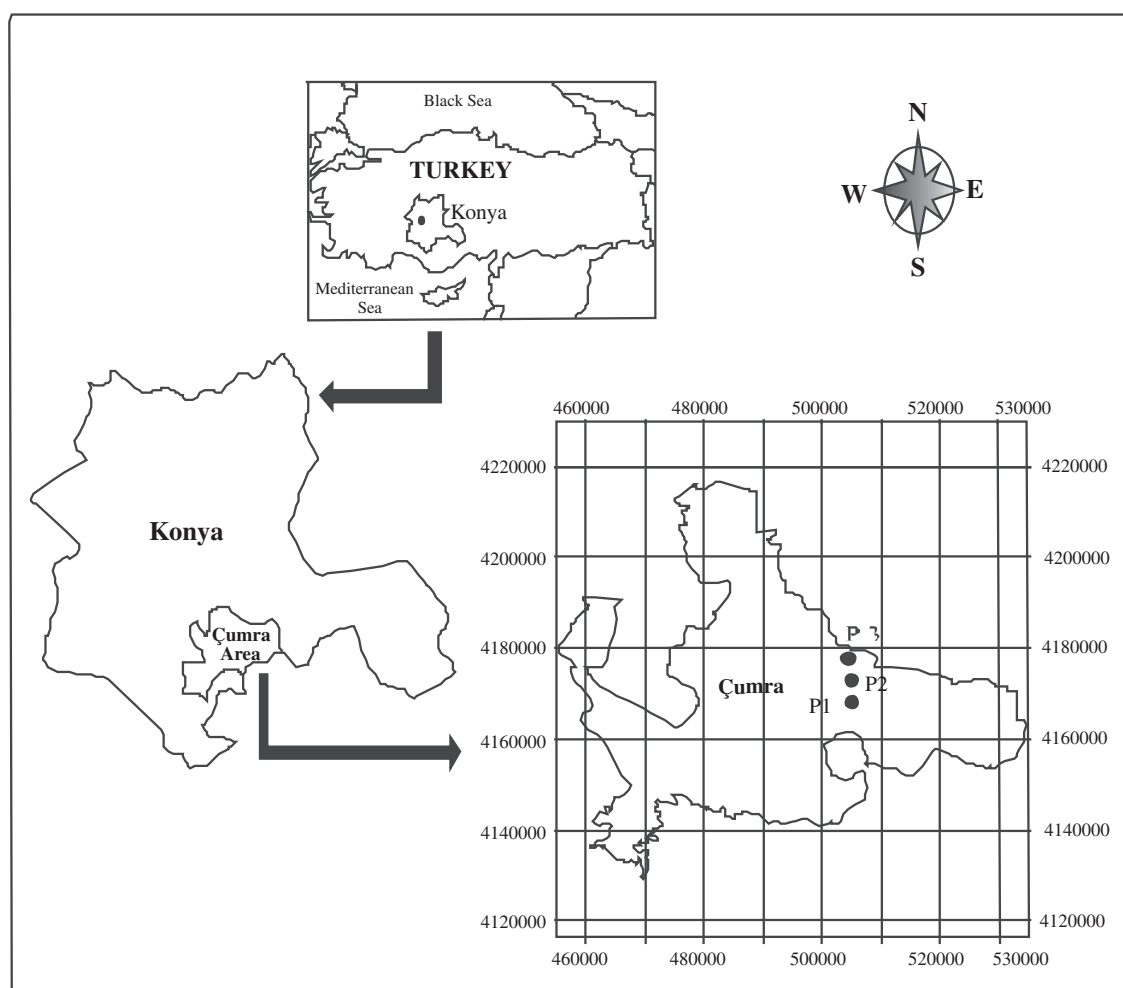


Fig. 1. Map of study area.

Table 1
Selected site characteristic of the studied pedons.

Pedon	Coordinates		Parent material	Elevation (m)	Physiography	Slope (%)
	Longitude	Latitude				
I	37°29'18"	32°44'14"	Hard limestone	1025	Terrace	5
II	37°31'41"	32°46'22"	Soft limestone	1018	Terrace	3
III	37°32'30"	32°49'23"	Soft limestone	1012	Terrace	2

32–358E and at an altitude of approximately 1000 m (Fig. 1). Several rivers flow into the Great Konya Basin, mainly from the south and the west. The physicochemical and mineralogical properties of the soils and sediments and the formation and diagenesis of carbonates under the lacustrine environment in the Great Konya Basin were extensively studied by de Ridder (1965), Driessen and de Meester (1969), Driessen (1970), de Meester (1970a,b, 1971), Muller et al. (1972) and Vergouwen (1981). The Great Konya Basin itself is filled by Quaternary sediments (de Meester, 1970b). During some periods of the Late Pleistocene epoch, most of the Great Konya Basin was covered by a shallow lake with a fairly constant water level of 12–20 m, which left a number of sandy beach ridges and sand plains located roughly at the 1010 m contour. On top of the soft-lime lake bottom, a large variety of other sediments were deposited, resulting in various physiographic units (de Meester, 1970a,b), which divided the Great Konya Basin plain into uplands, colluvial slopes, piedmont plains, bajadas, terraces, alluvial plains, and lacustrine plains. The terraces of the flat Neogene limestone are located along the fringes of the Konya Basin. They slope gently towards the centre and are locally dissected by erosion gullies. The alluvial plains and fans comprise the sediments of some rivers debouching into the southern part of the basin. The alluvial fans or inland deltas consist of sediments ranging from coarse sand to a heavy clay texture. The lacustrine plains are flat and contain carbonates. Deposited under water, the lacustrine plains cover vast areas in the centre of the Konya Basin. They are bordered by sandy beach ridges and shores at 1010–1020 m altitude. These ridges and shores were formed from the continual washing of the former Pleistocene lake, which is dated from 23 to 17 ka (Roberts et al., 1979; Roberts, 1983). According to the Konya meteorological station, the long-term records show that the mean annual precipitation is 468 mm, the total evaporation is 975.4 mm, the mean annual temperature is 10.8 °C, and the mean annual soil temperature at 50 cm is 13.1 °C (DMI, 1994). According to the climate data, the soil moisture and temperature regimes are xeric and mesic, respectively (Soil Survey Staff, 1999).

2.2. Soil sampling and analysis

For this study, three representative soil profiles were chosen on the Neogene-aged top terrace and the Quaternary-aged main side and bottom side terraces. Both disturbed and undisturbed soil samples were taken from the horizons after their macro-morphological identifications were completed.

The soil pH was measured potentiometrically in a 1:2.5 soil/water (w/v) suspension with a glass electrode (U.S. Salinity Lab. Staff, 1954). The electrical conductivity (EC) was determined potentiometrically in a 1/2.5 soil water suspension using a glass electrode (U.S. Salinity Lab. Staff, 1954). The particle size distribution was determined by the hydrometer method after the removal of organic matter using H₂O₂ and the addition of a sodium hexametaphosphate solution (Bouyoucos, 1951). The bulk density (BD) was determined by weighing the soil cores after they were dried for 24 h at 105 °C (Blake and Hartge, 1986). The organic matter in the soils was determined using the Walkley and Black wet digestion method (Van Lagen, 1993). The cation exchange capacity

(CEC) and exchangeable Ca, Mg, K, and Na were extracted using ammonium acetate (1 N, at pH 7). The quantity was determined using a flame photometer and an atomic absorption spectrophotometer (AAS) (Schollenberger and Simon, 1954). The amount of carbonate in the soil was measured using Scheibler calcimeters (Soil Survey Laboratory Methods Manual, 2004). Free Fe oxides were determined using dithionite-citrate bicarbonate (DCB) methods, and their amounts were measured using atomic absorption spectrometer ASS (Soil Survey Laboratory Methods Manual, 2004). For the respective methods, the cations were designated by the subscripts o and d. The total element analysis of the soil and rock samples was conducted by fusion with lithium metaborate (LiBO₂) and dilution in HNO₃–HF (Chao and Sanzalone, 1992), and the contents were measured using inductively coupled argon plasma (ICP). All the procedures were replicated three times for each soil, and the means were reported. An XRD analysis was also performed on powdered samples as randomly oriented powder mounts by the Shimadzu XRD-6000 with a Cu K α anticathode and K filter (40 kV, 35 mA). A diffractometric analysis of the pulverised saprolite and rock samples was carried out in the 2–40° 2 θ range (Jackson, 1979). The clay fraction (<2 μ m) was obtained from the soil after the destruction of the organic matter with dilute, Na-acetate buffered H₂O₂ (pH 5) by a dispersion with calgon and sedimentation in water. The oriented specimens on glass slides were analysed by X-ray diffraction using Cu K α radiation from 2° to 15° 2 θ with steps of 0.02° 2 θ at 2 s per step. The following treatments were performed: Mg saturation, ethylene glycol solvation (EG) and K saturation, followed by a heating for 2 h at 550 °C. The minerals and their relative abundance were identified by their diagnostic XRD spacing and then evaluated by their XRD relative peak intensities in the XRD diagram. The Chemical Index of Alteration (CIA) (Nesbitt and Young, 1982) and the Chemical Index of Weathering (CIW) (Harnois, 1988) were used to characterise chemical weathering in the soils. In addition to Eu and Ce, anomalies were used to assess the weathering rates of the studied soils.

3. Results

3.1. Morphological properties

A description of the study sites and the three representative soil profiles are presented in Tables 1 and 2. The soils of profile 1 are situated on an upper side terrace on steep slopes, the soils of profile 2 are situated on the main side terrace, and the soils of profile 3 are on the lower side terrace on slight slopes. All profiles occur on limestone at xeric soil moisture and mesic temperature regimes according to the climate data (Soil Taxonomy 1999). From the profile description, it is apparent that distinct soil horizons are lacking, with the exception of a weakly defined A and calcic B. The soils of profile 1 have a horizon sequence A-Btk-BC-C and shallow (approximately 65 cm), skeletal, and clay and sandy loam. The soils have a horizon sequence A-Bk-Ck and A-Bk-Ck-IIC (P21 and P3) and are shallow (approximately 74 cm) and clayey. All had strongly developed granular A horizons. In the B horizons, all of the profiles had a moderately to strongly developed angular blocky structure. In all of the profiles, the soil structure was massive or grade in the C layers.

Table 2
Selected morphological characteristics of profiles.

Pedon	Horizon	Depth (cm)	Colour dry	Colour moisture	Structure ^a	Field texture	Boundary	Biological activity ^b
I	A	0–13	10YR6/4	7.5YR4/6	mo, f, gr	C	Clear, smooth	h
	B1tk	13–33	10YR6/4	7.5YR5/6	mo, f, ab	C	Clear, smooth	m
	B2tk	33–48	10YR6/4	7.5YR5/6	mo, co, ab	C	Gradual, wavy	m
	BC	48–65	7.5YR8/1	7.5YR8/3	mas	SC	Clear, wavy	w
	C1k	65–104	7.5YR8/1	7.5YR8/3	mas	SC	Clear, smooth	n
	C2k	104–170	7.5YR8/2	7.5YR8/4	mas	SC	–	n
II	A	0–11	10YR7/4	10YR5/4	mo, f, pl	LC	Abrupt, smooth	m
	B1k	11–45	10YR6/4	10YR5/6	mo, co, ab	C	Clear, smooth	m
	B2k	45–81	10YR8/2	10YR8/3	Mo, co, ab	SC	Clear, smooth	m
	C1k	81–101	7.5Y8/1	5Y8/2	mas	C	Gradual, smooth	n
	C2k	101–180	7.5Y8/1	5Y8/2	mas	C	–	n
	III	A	0–25	7.5YR5/6	7.5YR4/6	st, co, gr	C	Clear, smooth
B1k		25–40	7.5YR5/6	7.5YR4/6	st, co, ab	CL	Clear, smooth	m
B2k		40–74	7.5YR7/4	7.5YR5/6	st, co, ab	C	Abrupt, smooth	m
C1k		74–120	7.5YR6/6	7.5YR5/6	mas	CS	Clear, smooth	w
C2k		120–161	7.5YR5/6	7.5YR4/6	mas	C	Abrupt, smooth	n
IIC3		+161	7.5YR5/6	7.5YR4/6	ga	S	–	n

^a Structure – w: weak; mo: moderate; st: strong; me: medium; f: fine; co: coarse; mas: massive; gr: granular; ab angular blocky; ga: grain; pl: platy.

^b Biological activity – n: none; w: weak; m: moderate; h: high.

In general, the upper mineral horizons were characterised by high organic carbon content (2.12–3.72%). The colour hue varied from 7.5 YR to 10 YR and was characterised by a higher value in deeper layers. Due to the presence of CaCO₃, a strong reaction with HCl was observed in the surface horizons. As a result, the soils studied classified as Aridisols. According to soil taxonomy, profile 1 is classified as Typic Calcargids, profiles 2 and 3 are classified as Typic Haplocalcids although placed in xeric regime. Because the area is located borders on aridic soil moisture regime and soils have aridic soil properties.

3.2. Physical and chemical properties

The main physical and chemical properties of the three profiles are presented in Table 3. All of the soils followed the general trend of having the highest organic matter content in the surface. The organic matter content ranged from the detection limit to 3.72%, and it declined rapidly with depth. All of the profiles contained high lime content, and the CaCO₃ content ranged from 22.6% to 77.9%. The lime content increased from the surface to C horizons. In profile 3, they decreased again at the IIC horizon because of lithologic discontinuity. The EC values of the soils ranged from 113 to 304 $\mu\text{S cm}^{-1}$, and all of the profiles were unsalted. The soil pH_(H2O) was alkaline in all of the profiles and ranged from 7.82 to 8.19. The CEC values ranged from 4.18 to 26.52 cmol kg^{-1} and showed no trend with depth. The CEC values correlated with the organic matter and the clay fraction contents. The exchangeable bases were generally present in the order of their abundance, with Ca > Mg > K > Na in the surface horizons and Ca > Mg > Na > K in the subsurface horizons. The exchangeable Ca + Mg, Na, and K ranged from 3.94 to 25.53 me g^{-1} , 0.09 to 0.90 me g^{-1} , and 0.12 to 2.59 me g^{-1} , respectively. The base saturation values were found to be 100%. The bulk density (BD) values of the soils ranged from 1.19 to 2.12 g cm^{-3} , with the surface soils generally having lower BD values than the subsurface soils. The lower BD values of the surface soils were attributed to the relatively higher organic C content of the surface soils. The value higher than 2 in profile 1 (C2k) could have been associated with the low weathering rate of the parent material. The texture of the soils was clayey and sandy clay loamy. The sand content ranged from 8.7% to 26.6%, the silt content from 29.0% to 57.1%, and the clay from 28.8% to 49.2%. The particle size distributions of the C horizons were not determined because of a very high CaCO₃ content in these layers. The sodium dithionite cit-

rate (DCB) extractable Fe is known as free Fe. The sodium dithionite citrate (DCB) extracts affected the crystallised materials and increased with the weathering. In the studied profiles, Fe_d ranged from 0.07% to 1.98% and decreased with depth. Some weathering rates, genetic rates and Eu and Ce anomalies are shown in Table 3. In the profiles, the CIA rate varied between 81.0 and 85.8, and no significant difference was found between the profiles. The CIA values increased with depth in profile 1, and no trend was found in the other profiles. The variation in the CIW values between the profiles was also limited. The CIW values ranged between 94.4 and 98.6 and tended to increase with depth. The Ce and Eu anomalies, which are indicators of weathering and oxidation conditions in soils, showed a homogenous distribution, and no significant differentiations were found between values. While negative Eu anomalies were found in the soils, a weak positive Ce anomaly was found in profiles 1–3. In the soils studied, the Eu and Ce anomalies ranged between 0.64–0.89 and 0.97–1.11, respectively.

3.3. Mineralogical properties

The X-ray diffractograms of the selected samples are shown in Fig. 2. No distinct differences in the clay mineral distribution with depth were observed, and pedons from all geomorphic surfaces had similar mineral components. The phyllosilicates of different amount and crystallisation degrees were found to have formed in all three profiles. In the clay fraction, three intensities were observed. The Mg saturated clay exhibited three intensity peaks at 1.44–1.40 nm, 0.95–1.00 nm, and 0.71–0.72 nm. The reflection at 0.72 nm disappeared at 550 °C. Glycolation expanded part of the 1.4–1.5 nm peak, with a shoulder at approximately 1.6–1.5 nm, and the same peak closed to 1.43–1.20 nm after K saturation at 20 °C; however, at 550 °C, an ill-defined diffraction band between 1.0 and 1.1 nm was observed, indicating the presence of smectite (S) with illite (I), and kaolinite (K). The XRD results for profile 1 revealed the following relationship: kaolinite > smectite > illite. For profile 2, the relationship was as follows: illite > kaolinite > smectite. Profile 3 yielded the following relationship: kaolinite > illite > smectite. The powder samples of the whole soils were also scanned from 2 to 40° 2 θ to determine the primer minerals. According to the X-ray diffractograms, the primary minerals such as feldspar (anortit, albit), calcite and quartz have been determined in the profiles.

Table 3
Some physical and chemical properties of studied profiles.

Pedon	Horizon	Depth (cm)	pH _(H2O) (1/2,5)	EC ($\mu\text{S}/\text{cm}^{-1}$)	Organic matter (%)	CaCO ₃ (%)	Fe _d (%)	CEC ($\text{cmol}_c \text{kg}^{-1}$)	Exchangeable cations ($\text{cmol}_c \text{kg}^{-1}$)		
									Ca + Mg	Na	K
I	A	0–13	7.93	172	3.17	22.6	1.16	21.20	18.51	0.49	2.20
	B1tk	13–33	7.82	120	0.54	27.0	1.01	24.61	23.55	0.57	0.49
	B2tk	33–48	7.90	113	0.92	26.2	1.34	26.52	25.53	0.59	0.40
	BC	48–65	8.10	124	0.43	27.8	1.54	24.13	23.08	0.61	0.44
	C1k	65–104	7.83	213	0.39	69.5	0.26	10.06	9.32	0.62	0.12
	C2k	104–170	7.90	131	0.00	42.9	0.46	14.31	13.35	0.74	0.22
II	A	0–11	7.95	171	3.72	30.2	0.91	20.93	17.85	0.49	2.59
	B1k	11–45	8.08	133	1.16	36.5	0.88	16.75	15.40	0.77	0.58
	B2k	45–81	7.98	167	0.75	61.6	0.34	8.81	7.79	0.90	0.12
	C1k	81–101	8.19	304	0.00	56.4	0.27	6.60	6.20	0.27	0.13
	C2k	101–180	7.89	244	0.00	77.9	0.07	4.18	3.94	0.09	0.15
III	A	0–25	7.94	187	2.12	17.1	1.42	27.43	24.60	0.67	2.16
	B1k	25–40	7.93	167	0.92	19.8	1.48	23.04	21.47	0.15	1.42
	B2k	40–74	8.10	157	0.63	29.4	1.13	15.45	14.55	0.04	0.86
	C1k	74–120	7.94	158	0.43	33.8	1.05	16.35	15.58	0.13	0.64
	C2k	120–161	8.03	157	0.00	22.2	1.51	21.05	20.21	0.27	0.57
	IIC3	+161	8.07	178	0.00	16.3	1.62	18.06	16.74	0.71	0.61
Pedon	Horizon	Depth (cm)	Base saturation (%)	CIA	CIW	Eu/Eu*	Ce/Ce*	Bulk density (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)
I	A	0–13	100	81.3	94.4	0.76	1.08	1.57	25.3	45.8	28.9
	B1tk	13–33	100	83.5	95.7	0.70	0.97	1.48	26.6	29.0	44.4
	B2tk	33–48	100	83.8	95.8	0.64	1.04	1.49	16.9	36.2	46.9
	BC	48–65	100	83.7	95.7	0.65	1.05	1.46	17.6	37.2	45.2
	C1k	65–104	100	85.3	95.7	0.70	1.02	1.72	–	–	–
	C2k	104–170	100	85.8	98.6	0.77	1.05	2.12	–	–	–
II	A	0–11	100	81.0	96.0	0.70	1.03	1.29	16.4	50.9	32.7
	B1k	11–45	100	82.4	96.6	0.83	1.02	1.19	12.5	54.5	33.0
	B2k	45–81	100	83.1	95.8	0.74	1.03	1.19	11.1	57.1	31.8
	C1k	81–101	100	83.2	97.1	0.67	1.06	1.41	–	–	–
	C2k	101–180	100	82.0	97.0	0.65	1.01	1.36	–	–	–
III	A	0–25	100	83.6	96.9	0.85	1.06	1.44	15.8	43.5	40.7
	B1k	25–40	100	83.8	96.9	0.74	1.04	1.41	17.1	38.6	44.3
	B2k	40–74	100	84.5	96.6	0.89	1.06	1.42	12.1	38.7	49.2
	C1k	74–120	100	85.5	97.3	0.69	1.10	1.25	8.7	52.7	38.6
	C2k	120–161	100	84.4	97.0	0.70	1.06	1.39	–	–	–
	IIC3	+161	100	84.1	96.6	0.68	1.11	1.67	–	–	–

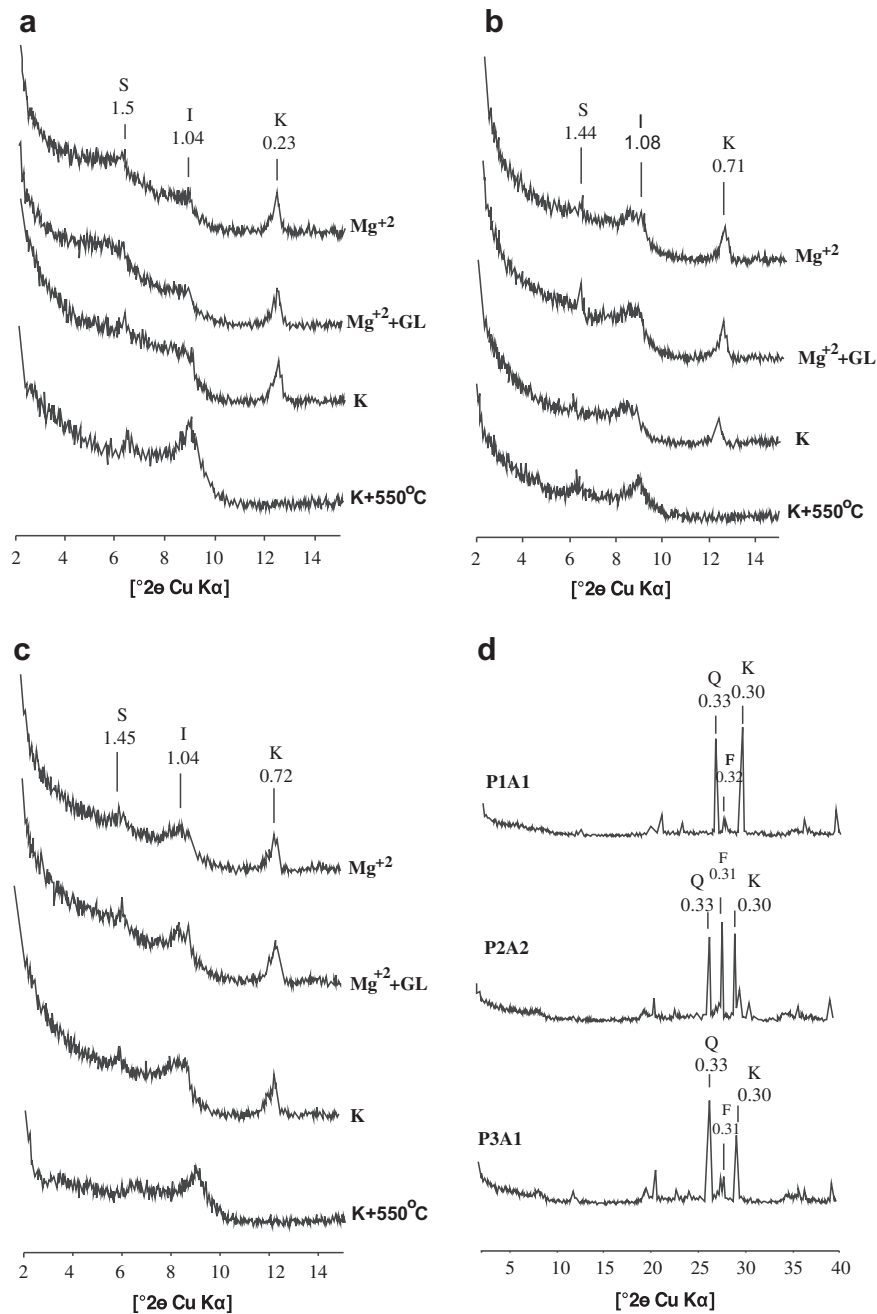


Fig. 2. X-ray diffractograms of selected samples: (a, b, c) in clay fraction (a) P1-A1; (b) P2-A1; (c) P3-A1, S: Smectite, I: illite, K: kaolinite, *d*-in nm (d: primer minerals, (F) Feldspar; (Q) Quartz; (K) Calcite), *d*-in nm.

4. Discussion

4.1. Morphologic properties

The profiles in the study field are soils on the Neogene age upper coastal terraces (1025 m), the main coastal terraces (1018 m), and the low Coastal terraces (1014 m). Profile 1 was formed on hard limestone, while profiles 2 and 3 were formed on soft limestone. All three profiles are used as pasturelands. As can be understood from the profile identifications, in addition to the A horizon, a calcic B horizon exists that developed weakly. Additionally, in profile 1, which developed on the oldest terraces, an argillic horizon was determined. Profile 1 was on the Neogene terrace and the other two were Quaternary age terraces, which

allowed for the clay washing in profile 1. However, the fact that the weathering rates and the anomalies are very close indicates that these clays were formed not as a result of neoformation but with an inheritance from the main material. The erosion that resulted from the upper coastal terrace's higher slope and formation on hard limestone caused the formation of the thinner A horizon and a more superficial CaCO₃ limestone accumulation despite the fact that the soil formation took longer. Profile 1 is generally clay textured; profile 2 and profile 3 have loamy textures; and profiles 1 and 3 have granular textures in the A horizons. The angular blocks are in the B horizons. The C horizons are grainy or massive. In all of the profiles, a strong HCl reaction was observed on the surface and subsurface horizons. Although there was a lime movement in the profiles, there was not enough rainfall to completely

account for the washing up of CaCO₃ in the A horizon. Contrary to expectations, the calcic horizon was the deepest in profile 3 because the negative effect of erosion resulting from the high slope in the upper and main coastal terraces on the A horizon thickness.

Generally, the existence of high clay content and a clay and silty clay loam soil texture class is compatible with the sedimentary characteristics of the region. The bulk density of the soils is lower on the surface and increased towards the main material. This case resulted from the presence of organic material on the surface. Additionally, the amount of the clay horizons has also been influential on the bulk density values.

4.2. Physical and chemical mineralogical characteristics

In all three profiles, the clay contents are high, and the texture classes are clay and silty clay loam. The terraces in the study field were on Neogene-age limestone and enter into the basin in the shape of a finger. They are inclined towards the centre and were incised with erosion gullies. The soils formed in this location are composed of fine materials carried from the high lands by water and gravity. These fine materials are carried towards the centre of the basin with small gullies. Particularly, lower coastal terraces and lower alluvial plains and fans are composed of sediments carried by various streams entering the basin from the south. They have various textures, ranging from rough sand to heavy clay. Therefore, the soils examined are compatible with the sedimentary characteristics of the region. The organic materials in the soil are formed as a result of the decomposition of plant roots and micro-organisms, which is a very significant factor in mineral alteration. The organic acids with a low molecule weight in the soil organic material have a very important role in weathering; thus, by forming many complexes and ligands on the mineral surface, these acids have an important role in soil genesis (Fox, 1995).

In the soils in the study field, the organic material (especially on the surface horizons) rose as high as 3.17%, which can be regarded as high for a dry region in our country. However, this rate is low in general. Low rainfall and a long and dry summer season prevented the organic material from reaching a higher level. Moreover, the organic material content decreased significantly with depth and decreased to very low levels after the surface horizons. The lowest organic material content was in profile 3 and the organic material content decreased as terrace level decreased, which is compatible with the ages of profiles. When the soil reaction in the soil profiles was examined, the high pHs were observed to be dependent on the composition of the parent material and on whether there are minerals providing basic cations. Due to the nature of the parent material and carbonates, the pH in water in these soils was above 7 in all of the horizons. The CEC values of the soils in the study field ranged between 4.18 and 27.43 me 100 g⁻¹, and despite the low organic material, the high values were reached in some horizons. Such high levels of CEC indicate the presence of stratified aluminosilicates (smectite) with high load intensity. The X-ray diffractions taken from the chosen profiles verify this situation. Other factors verifying this situation are the region's climate, the high Ca and Mg presence in the profiles and the high SiO₂/Al₂O₃ rates. While the basic cations in the soils were Ca + Mg > K > Na on the surface in terms of abundance, they changed to Ca > Mg > Na > K in the deep. This case indicates that the feldspars were plagioclase, which suggests that Na and Ca are rich minerals in the parent materials. The higher levels of K on the surface were due to the plant cycle. Despite the composition of the parent main materials weathering of plagioclase, the soil colloids were saturated with Ca and Mg, and the base saturation was 100%. A base saturation of 100% indicates that low rainfall was not an adequate wash base. All of the profiles examined are unsalted and their distribution in the profile is irregular.

However, depending on the effectiveness of the washing, the lowest saltiness was on the surface horizons upper coastal terrace profile, and the highest saltiness was in the low coastal terrace. All of the profiles studied were formed on limestone parent material, which led to higher limestone content in the profiles. Lower rainfall in the region prevented the complete washing off of the lime from the profile. However, the lime was subjected to a significant amount of washing off in all three profiles, particularly in profile 1, which was formed on the Neogene-age high coastal terrace. The lime content tends to increase with depth in accordance with the fact that the profiles are of calcareous parent material. The fact that lime was not subject to a heavy washing off prevented a marked clay movement due to the Ca saturation in the younger main coastal terrace and the lower coastal terrace.

According to Dahlgren et al. (1993), a high free iron (Fe_d) content indicates that the meta stable ferrihydrite changed thermodynamically into the stable Fe-oxides like goethite and hematite. The Fe_d distribution in profiles generally decreased with depth as a function of weathering. In the profiles studied, the weathering rate tends to decrease from the surface to deep.

The diversification in the decrease with depth in profile 3 is most likely related to a lithologic discontinuity. The Fe_d value is high in the profile formed on the upper coastal terrace and in the one formed on the main coastal terrace, which is comparable in age. However, although it was the youngest, the highest values were in profile 3. This situation results from the fact that profile 3 was influenced by the sedimentation design in the alluvial soils because it is very close to the Çarşamba brook accumulation conic, which goes through the region and forms the Çarşamba's alluvial fan.

The CIA is based on the progressive removal of the soluble cations (e.g., Ca, Na, and K) from the minerals during the chemical weathering, and it reflects the proportion of primary and secondary minerals in the bulk sample. The CIA represents the degree of the alteration of feldspars to clay minerals in the course of hydrolytic weathering, and it indicates the relative content of clay minerals. The soils and sediments derived from intensely weathered rocks and containing residual clay minerals such as kaolinite and/or gibbsite have CIA values approaching 100, and unweathered upper crustal rocks have a CIA value of 50 (Fedo et al., 1995). This ratio ranged from 70 to 75 for shales.

The studied soils have CIA values of 80–85. When the CIA values are classified as very slightly weathered (50–60), slightly weathered (60–70), moderately weathered (70–80), highly weathered (80–90), and extremely weathered (90–100), it is evident that although all of the soils in the study field are developed on different terrace levels, they are all in the same class.

The fact that there is a limited variation range in CIA values along the profiles, that the profiles are in the same class, and that the soils have a similar structure in general though there are small differences in the chemical characteristics, and particularly in the clay and lime content and in horizon order indicates that the soils have undergone a similar weathering process and that the weathering levels are similar, although the soil formation took a different time depending on the terrace level.

The CIW value ranged from 50 to 100 in the soil from an unweathered rock to an intensively weathered rock. The value increased with weathering. The CIW displayed similar behaviour for the profiles in this study. If the classification for CIA is performed for CIW as well, it is evident that all the profiles developed in different terrace levels are in the same class in terms of CIW values. This result indicates that although some small morphological differentiations exist, the soils studied have similar weathering conditions.

Ce and Eu can occur in different oxidation states and often show greater fractionation relative to the other REE. In the form of

normalised plots, the rare earth element (REE) data have been widely used to compare the distribution of REE patterns in different environment (Evensen et al., 1978). The values normalised against the common references allow us to characterise samples and to compare their fractionalisation levels and anomalies in their amounts (Rollinson, 1993). For this purpose, the Eu and Ce anomalies were also investigated in the study area.

The Europium anomalies are estimated by comparing the measured concentration of Eu with an expected concentration of Eu^* obtained by the interpolation between the normalised values of Sm and Gd, as proposed by Taylor and McLennan (1985):

$$Eu/Eu^* = Eu_N / \sqrt{(Sm)_N \times (Gd)_N}$$

In all of the profiles, the Eu anomalies were negative and very close to each other. The similarity of the negative Eu anomalies and their values in the profiles developed on different terraces levels indicates the existence of low and similar weathering conditions. The fractionation of Ce is known to occur during weathering and sedimentary processes. In the initial stages, the negative Ce anomalies are observed in weathering products such as the secondary hydrous phosphates (Braun et al., 1998), and the positive Ce anomalies appear in intensely weathered lateritic profiles where the soluble Ce^{3+} oxidises to an insoluble, thermodynamically stable Ce^{4+} and accumulates in secondary cerianite, $Ce(IV)O_2$ (Pan and Stauffer, 2000). The cerium anomalies are estimated by comparing the measured concentration of Ce with an expected concentration of Ce^* obtained by an interpolation between the normalised values of La and Pr:

$$Ce/Ce^* = Ce_N / \sqrt{(La)_N \times (Pr)_N}$$

Like Eu/Eu^* , the Ce anomalies showed a small differentiation between the profiles. The homogenous and relatively small Ce anomaly of the studied soil samples ($0.92 Ce/Ce^* < 1.1$) indicated that the chemical weathering that they underwent was similar and not intensive.

The clay minerals are formed in two main processes. In the first process, the clay minerals are generated as an alternation product through hydrothermal events. In the second process, the minerals are formed through weathering. The clay minerals resulting from weathering are determined by the main rock, the climate, plant cover and the duration of time (Dizdar, 1979). In the clay fraction of the soils, there can be one or several clay minerals. However, in general, one of them is dominant and is influential with its characteristics, especially in relation to the soil properties. The clay minerals can be formed directly from main rock, or they can be formed in the soil and change from one type to another in this environment. In each of these profiles, the type of clay minerals in the clay fractions on the surface horizons remained the same; however, the dominant clay minerals changed slightly, while the amount and type of the primary minerals remained the same. This finding indicates that the pedogenic diversification between the profiles is very limited, although they are at different terrace levels.

5. Conclusion

Although the soils in the study field were formed in different terrace levels, no significant relationship between the age and the soil characteristics was found. The lone exception for clay movement in the upper terrace can be observed in profile 1, which resulted from the limitation in profile growth caused by erosion. Moreover, this erosion was the result of an increasing slope from the low terrace to the high coastal terraces. However, the fact that the physical, chemical and mineralogical characteristics in the profiles are similar and had limited variation and that the weathering indexes and anomalies determined using geochemical

characteristics showed a very limited variation along profiles indicates that the profiles show similar weathering levels despite their different ages. This situation indicates that the pedologic processes occurring along the Holocene in the Konya Plain, in which Ancient Lake Konya is located, were not intense enough for the soil formed on a calcic Chronosequence to diversify in the region. Moreover, the increasing slope and erosion towards the upper coastal terrace eliminated the effect of the limited diversification that resulted from the difference in age. In other words, the climatological factors along the Holocene were not influential enough to change the effect of other soil formation factors significantly. Therefore, it was concluded that the main factors determining soil formation are climate and topography, both of which determine the washing regime and weathering levels.

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