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Clay Mineralogy of the Upper Cretaceous-Lower Tertiary sedimentary sequences of the Kalecik Region (Central Anatolia, Turkey)

Kalecik Bölgesi Üst Kretase-Alt Tersiyer sedimanter istiflerinin kil mineralojisi (Orta Anadolu,Türkiye)

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ABSTRACT

The study area is located to the northeast of Ankara city. The Upper Cretaceous and Tertiary sedimentary units unconformably overlie the ophiolitic basement rocks in the area. Samples were collected along the measured stratigraphical sections in the investigated area. X-ray analysis techniques were used for distinguishing the Upper Cretaceous-Tertiary sequence with clay minerals. The aim of this study is to clarify the origin of the clay mineral properties of these successions. Smectite is the dominant clay mineral in the Upper Cretaceous units. In Paleocene units, smectite and 14S-14C are abundant minerals. In Lower Eocene units, smectite and corrensite are found. Smectite and kaolinite were determined in the Middle Eocene series. Illite and chlorite were found in lesser amounts in the whole sequence. Major and trace element analyses were carried out on clay fraction, and structural formulas were calculated. The smectites were determined as beidellite and saponite. Major and trace element analyses revealed that the sediments have derived from two different sources namely, ultramafic and metamorphic rocks.

Key Words: Clay mineralogy, Cretaceous, Kalecik, Tertiary, Turkey.

ÖZ

Çalışma alanı, Ankara'nın kuzeydoğusunda ve Üst Kretase-Tersiyer yaşlı sedimanter birim ofiyolitik temelin üzerinde uyumsuzlukla yer almaktadır. Çalışma alanında, örnekler ölçülü stratigrafik kesitler boyunca alınmış ve Üst Kretase-Tersiyer istifinin kil mineralleri X-ışınları analiz teknikleri ile tanımlanmıştır. Kil minerallerinin kökeninin aydınlatılması bu çalışmanın amacını oluşturmaktadır. Simektit Üst Kretase birimleri içinde hakim mineral olarak belirlenmiştir. Paleosen birimleri içinde simektit ve 14S-14C en bol bulunan minerallerdir. Alt Eosen yaşlı birimlerde simektit ve korensit, Orta Eosen yaşlı birimlerde simektit ve kaolinit tespit edilen minerallerdir. İllit ve klorit tüm istif boyunca az olarak tespit edilmiştir. Kil fraksiyonunun ana ve eser element analizleri yapılarak simektitlerin yapısal formülleri hesaplanmış ve simektitler baydelit ve saponit olarak belirlenmiştir. Ana ve eser element analiz sonuçlarına göre, sedimanlar ultramafik ve metamorfik olmak üzere iki farklı kaynaktan türemişlerdir.

Anahtar Kelimeler: *Kil mineralojisi, Kretase, Kalecik, Tersiyer, Türkiye.*

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INTRODUCTION

The study area is located to the northeast of the city of Ankara (Figure 1). In this region, a number of studies have been conducted for a variety of purposes, such as general geology (Erol, 1954); biostratigraphy (Tekkaya et al., 1975), mineralogy and petrography (Ataman et al., 1976; Ataman and Gündoğdu, 1980). A detailed stratigraphical study of the region has been carried out by Çapan and Buket (1975). However, except for the study performed by Bayhan (1981), no detailed research into the clay mineralogy in the area has been carried out. The aim of this research is to determine the clay mineralogy, geochemical properties and the origin of the clay minerals in the Upper Cretaceous-Lower Tertiary formations. For this purpose, samples were taken from measured stratigraphical sections and determined using an X-ray diffractometer.

STRATIGRAPHY

The Upper Cretaceous-Tertiary sedimentary sequences are widely exposed in the study area (Figure 2). The Lower Cretaceous-Campanian Aktepe-Gökdere formation with ophiolithic melange characteristics is located at the base (Çapan and Buket 1975). The Campanian Bulduk Tepe formation unconformably overlies the Aktepe-Gökdere formation and consists of analcime bearing volcanic rocks. The Maastrichtian Kenanındere formation unconformably overlies the Bulduk Tepe formation. The bottom levels of this formation are represented by limestones and conglomerates. Sandstones are observed at the middle levels, and in the upward direction marls are observed. The Sakızlık Tepe formation unconformably overlies the Kenanındere formation and consists of compact limestones. At the base of the Tertiary sequence, the Lower Paleocene aged Tatarilyas formation (conglomerate, sandstone and marl alternation) is found. The Lower Eocene aged Kışlabağtepe formation unconformably overlies the Tatarilyas formation, and at its bottom conglomerates appear and grade into sandstones. The Lutetian aged Yanıkkafatepe formation which is conformable with the lower unit, consists of yellow fosillifereous limestone. The Oligocene aged Kazmaca formation, Neogene and Quaternary units unconformably lie on the older sedimentary units.

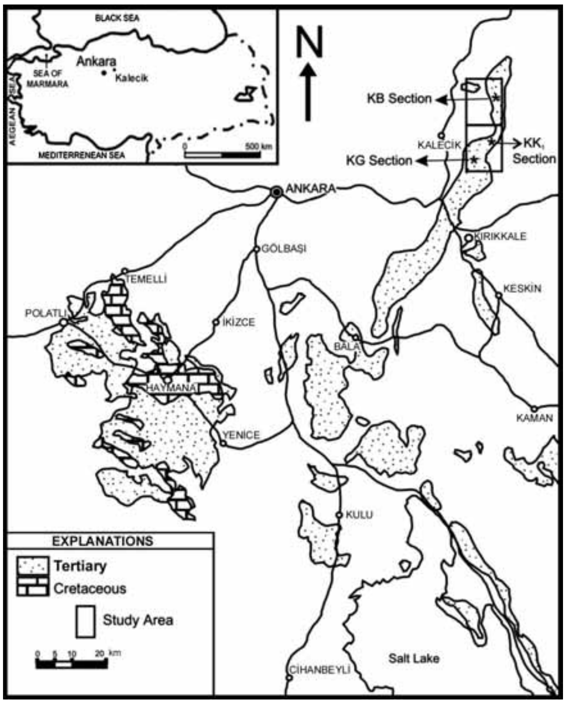

Figure 1. Location map of the study area (after Çapan and Buket, 1975).
Şekil 1.Çalışma alanının yer bulduru haritası (Çapan ve Buket, 1975'den alımıştır).

SYSTEM	SERIES	STAGE	FORMATION	LITHOLOGY
Quaternary				Alluvium
NEOGENE	Pliocene		Kağnı Tepe	Conglomerates
	Miocene		Kabak Tepe	Dasitic to andesitic tuffs
PALEOGENE	Oligocene		Kazmaca	Red conglomerate, sandstone, marl alternations with gypsium inner layers
	Eocene	Lutetian	Yanıkkafa Tepe	Yellow, fossilfereous limestones
		Ypresian	Kışlabağ Tepe	Conglomerate, marl and sandstone alternations
	Paleocene		Tatarilyas	Conglomerate, marl and sandstone alternations
CRETACEOUS	Upper Cretaceous	Maastrichtian	Sakızlık Tepe	Limestones
			Kenanındere	Conglomerate, marl and sandstone alternations
		Campanian	Bulduk Tepe	Volcanics with analcime
	Lower Cretaceous		Aktepe-Göktepe	Ophiolitic melange

Figure 2. Stratigraphic sequence of the study area (after Çapan and Buket, 1975).
Şekil 2. Çalışma alanının stratigrafik istifi (Çapan ve Buket, 1975'den alımıştır).

MATERIAL AND METHOD

The study was carried out in two steps, namely, field and laboratory studies. Three stratigraphic sections were measured and 112 samples were collected from these sections. Clay fraction was seperated on the basis of Stokes' law. Clay minerals were analysed under air-dried (AD), ethylene glycolated (EG), and heated (500^0 C, for 4 hours) conditions, and were determined based on d (001) reflections according to Brown (1961), Millot (1970), Brindley (1980), Wilson (1987), and Moore and Reynolds (1987). A Phillips 1140 model X-ray difractometer with CuK· radiation and Ni filter was used for determining clay fraction minerals. The percentages of clay minerals were calculated according to the method suggested by Temel and Gündoğdu (1996). Geochemical analyses were made using a Philips 1480 model X-ray flouresence spectrometer (XRF) according to the method recommended by Temel et al. (1998), and scanning electron microscopy (SEM) studies were made to determine micromorphological features of the clay minerals.

CLAY FRACTION MINERALOGY

The variation of clay mineralogy along the three measured sections are given in Figures 3, 4, and 5. Smectite (80-100 %) is the dominant clay mineral in the Upper Cretaceous unit (Figure 3). Although illite and chlorite are the other clay minerals, they are present only in trace amounts. Smectite is found in all samples. In the Paleocene units, smectite, corrensite, 14S-14C, illite and chlorite are determined in the sediments. While smectite and corrensite are the dominant clay minerals, illite, chlorite and 14S-14C are the other clay minerals.The amount of smectite increases towards the lower part of the Tatarilyas formation, while corrensite increases in the upper part (Figures 3, 4 and 5). In the Lower Eocene Kışlabağtepe formation, smectite and corrensite are observed in large quantities, smectite is the most abundant clay mineral at the lower part of the formation. Their SEM images are given in Figure 6. As seen from this figure, the folded-lamellar smectites have developed within matrix and on the feldspars. Moving upwards, corrensite becomes the major component. Illite and chlorite are the other clay minerals found in minor quantities (Figures 4 and 5). In the Middle Eocene Yanıkkafa Tepe formation, smectite and kaolinite are present in high quantities, while only small amounts of illite and chlorite are usually found (Figures 3, 4 and 5). The vertical stratigraphical distribution of clay fraction mineralogy in the study area is given in Table 1.

CHEMICAL ANALYSIS RESULTS

A major element chemical analysis of clay fraction is given in Tables 2 and 3. The structural formula of smectites was calculated according to Weaver and Pollard (1973) based on 11 oxygen (see Table 2). Four samples were identified as beidellite which is dioctahedral smectite (KB1-02, KB1-05, KB1-06, KB1-08), and these samples belong to the Maastrichtian aged Kenanındere formation. The others are saponite, and trioctahedral smectite (KB1-01, KB1-03, KB1-04, KB1-28). Among these samples, only KB1-28 was taken from the Lower Paleocene Tatarilyas formation and the others belong to the Maastrichtian Kenanındere formation. The results of analyses of non-monomineralic clay fractions are shown in Table 3. Samples KB1-11, KB1-12, KB1-18, KB1- 30 and KG-45 are taken from the Paleocene aged Tatarilyas formation, and KG-21 and KG-41 belong to the Lower Eocene Kışlabağ Tepe formation. Clay fractions of the KB1-11 and KB1-12 sandstone samples are rich in Al_2O_3, while the other clay fractions which are extracted from sandstone samples (KB1-18, 30, KG-21, 41,45) are rich in MgO. Positive correlations are observed between Al_2O_3-K_2O, Fe_2O_3-MgO, TiO_2-Fe_2O_3 and negative correlations are observed between Al_2O_3-MgO. This result

Table 1. Abundance of clay minerals in the study area.
Çizelge 1. Çalışma alanında kil minerallerinin bollukları.

Age	Clay minerals					
	Smectite	Corrensite	Kaolinite	Illite	Chlorite	14s–14C
M. Eocene	++	-	+++	+	+	+
L. Eocene	+++	+++	-	+	+	+
Paleocene	+++	++	-	+	+	+
U. Cretaceous	+++	-	-	+	+	+

+++ very abundance, ++ less abundance, + very few abundance, - none is correlated with the di- or tri-octahedral clay mineral composition. The amounts of Al_2O_3 and MgO are high in the Cretaceous sediments, while the values of Fe_2O_3 and MgO are high in most of the Paleocene and Lower Eocene sediments. The trace element chemical analysis results obtained from three clay fractions are given in Table 4. The clay fractions of two samples, which include more corrensite, have high Ni, Co, Cr and low Ba values, which

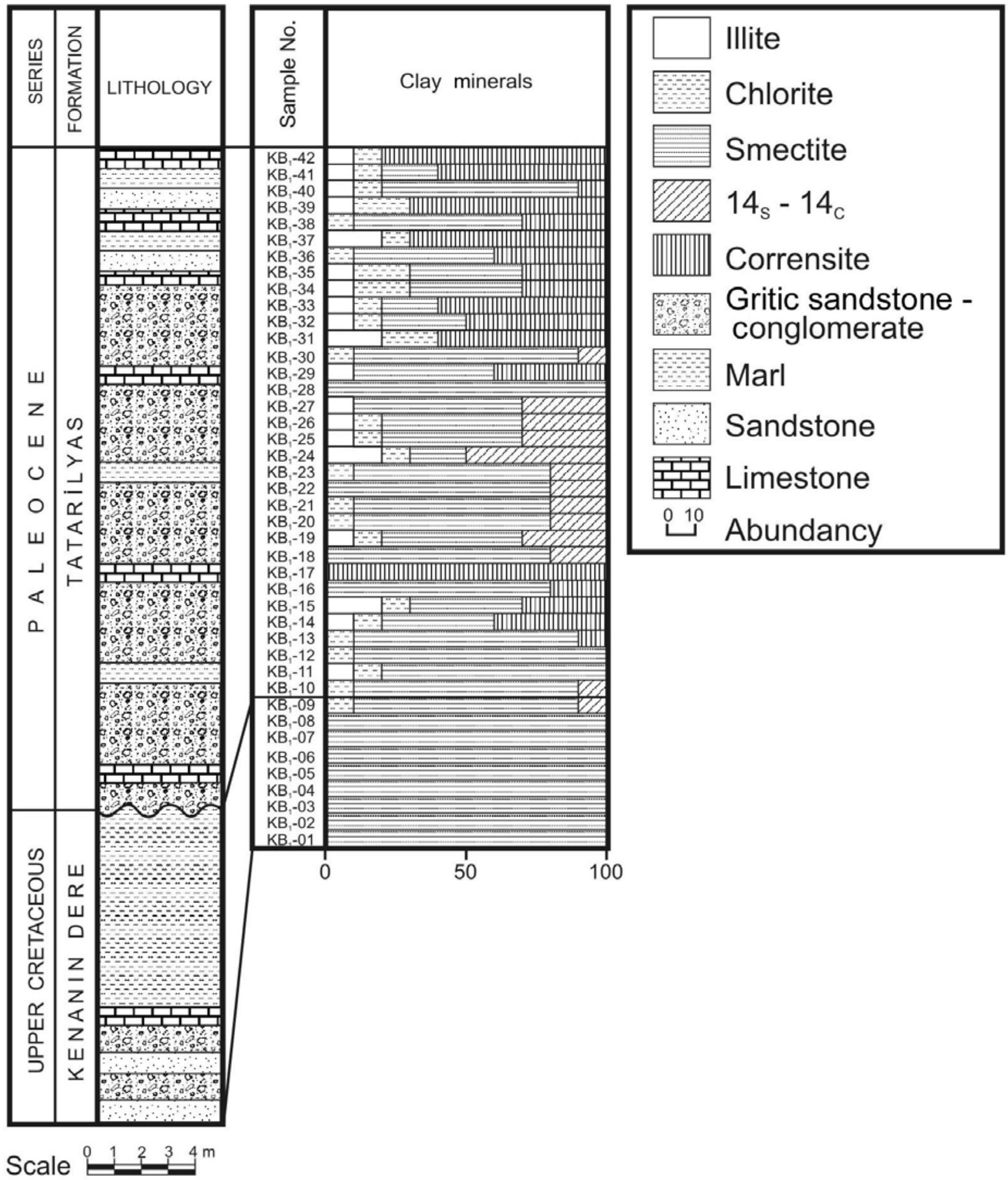

Figure 3. Clay mineral distribution of the KB_1 measured stratigraphical section taken from the study area (Sheet number: Çankırı H31-d1, Coordinates: 49_9 43_4-49_7 43_7, 51_9 42_9-51_8 42_9).

Şekil 3. Çalışma alanından ölçülen KB_1 stratigrafik kesitine ait kil mineral dağılımı (Pafta numarası: Çankırı H31-d1, Koordinatlar: 49_9 43_4-49_7 43_7, 51_9 42_9-51_8 42_9).

are related with ferromagnesian minerals. However, the beidellite-rich sample (Table 4) has lower Ni, Co, and Cr values and higher Ba, Al, and K values, which are related to feldspar and/or mica minerals. The geochemical properties of these clay minerals indicate the presence of different source rocks along the sequence in the study area.

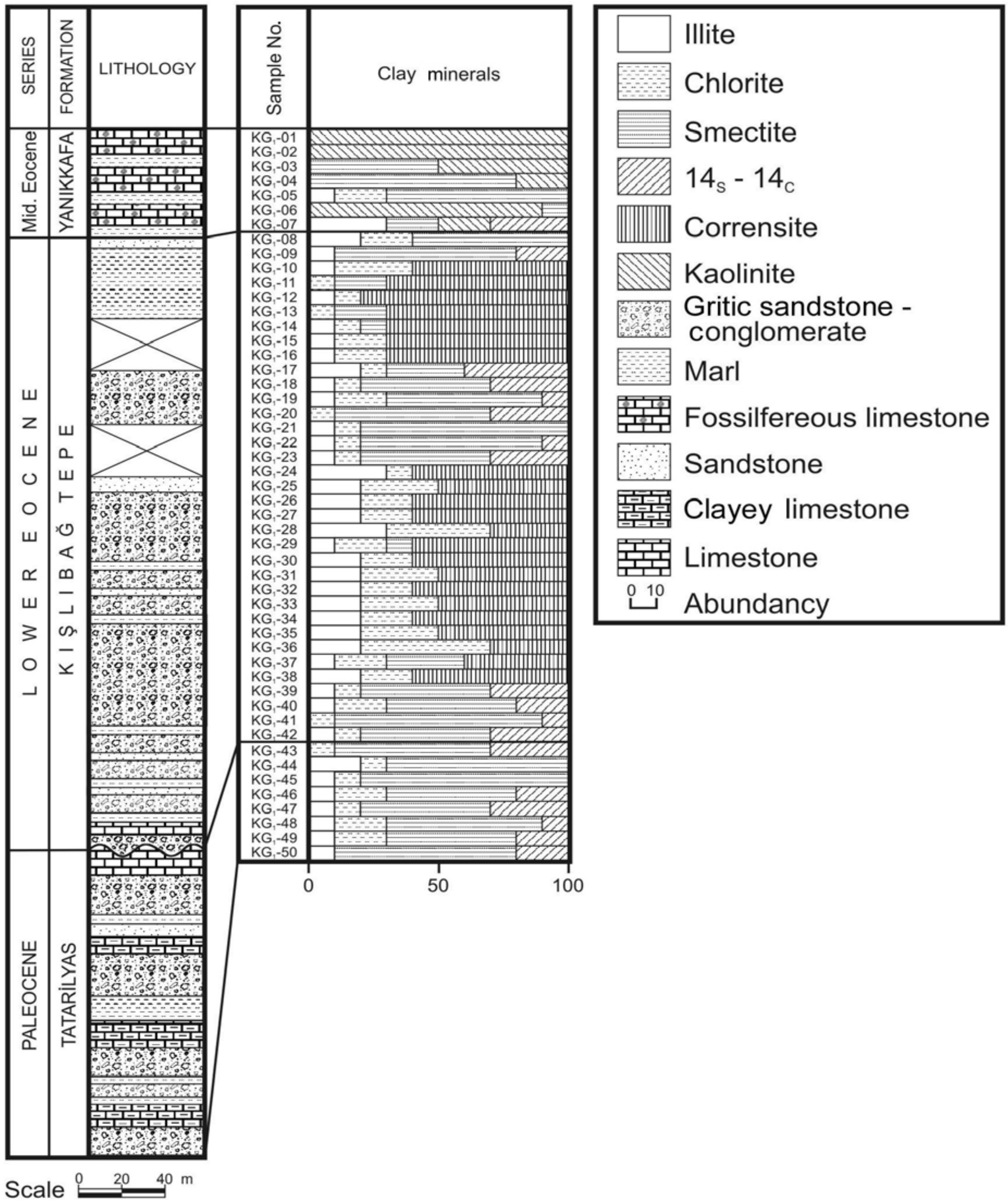

Figure 4. Clay mineral distribution of the KG_1 measured stratigraphical section taken from the study area (Sheet number: Çankırı H31-d4, Coordinates: $45_4\ 34_9$-$46_8\ 37_7$).

Şekil 4. Çalışma alanından ölçülen KG_1 stratigrafik kesitine ait kil mineral dağılımı (Pafta numarası: Çankırı H31-d4, Koordinatlar: $45_4\ 34_9$-$46_8\ 37_7$).

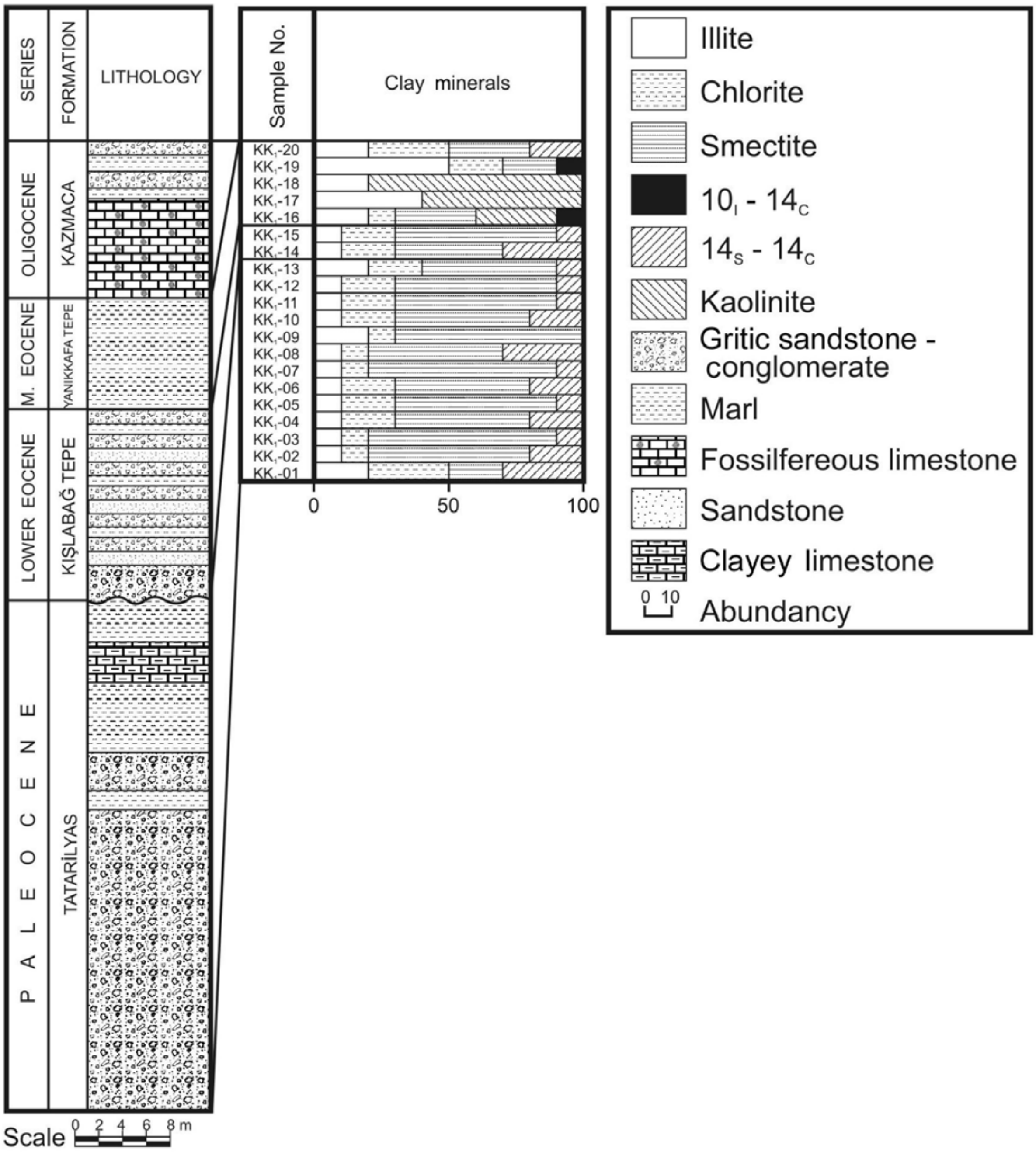

Figure 5. Clay mineral distribution of the KK$_1$ measured stratigraphical section taken from the study area (Sheet number: Çankırı H31-d4, Coordinates: 48$_0$ 37$_6$-48$_0$ 37$_2$).

Şekil 5. Çalışma alanından ölçülen KK$_1$ stratigrafik kesitine ait kil mineral dağılımı (Pafta numarası: Çankırı H31-d4, Koordinatlar: 48$_0$ 37$_6$-48$_0$ 37$_2$).

DISCUSSION

In the study area, smectite was found in the Upper Cretaceous, while smectite and 14S-14C associations were determined in the Paleocene units in abundance. In the Lower Eocene units, smectite and corrensite associations were dominant, whereas smectite and kaolinite assemblage were largely found in the Middle Eocene sequence. Illite and chlorite were determined always in minor amounts along these sequences. Major and trace element analyses indicate that beidellitic smectites could have been derived from the alteration of mica and feldspars (Figure

6) from magmatic rocks as reported by Chamley (1989) and Millot (1970). Trioctahedral saponites are rich in Mg, Fe and Ti. In the detrital units, high contents of Fe and Ti may indicate that they have been formed from in-situ transformation of the clastic material from the ultramafic rocks. High abundances of Ni, Co and Cr in corrensite also show the presence of ultramafic rocks in the

Table 2. Results of the chemical analyses of the smectites.
Çizelge 2. Simektitlerin kimyasal analiz sonuçları.

Sample No.		KB_1 – 01	KB_1 – 02	KB_1 – 03	KB_1 – 04	KB_1 – 05	KB_1 – 06	KB_1 – 08	KB_1 – 28
Oxides (%)	SiO_2	51.05	54.55	52.62	50.45	49.88	56.12	55.15	51.20
	Al_2O_3	12.75	16.23	12.79	11.27	17.97	15.84	20.02	11.17
	MgO	9.38	6.71	10.62	12.48	6.27	3.49	2.10	12.02
	CaO	0.64	0.36	0.64	1.29	0.70	0.39	1.07	0.77
	Fe_2O_3	11.88	8.33	11.56	10.65	10.56	12.30	9.18	11.42
	MnO	0.07	0.05	0.08	0.05	0.03	0.00	0.01	0.07
	TiO_2	1.06	0.59	0.72	1.03	0.92	0.83	0.92	0.91
	Na_2O	1.12	0.56	0.64	0.50	0.17	0.96	0.48	1.30
	K_2O	2.49	2.55	2.72	2.01	3.06	2.77	1.80	1.02
	P_2O_5	0.50	0.00	0.00	0.16	0.00	0.20	0.00	0.20
	LOI	8.46	7.72	7.64	8.65	7.51	8.07	7.66	8.40
Total	99.40	97.65	100.03	98.54	97.07	100.97	98.39	98.48	
Tetrahedral	Si+4	3.58	3.73	3.60	3.55	3.49	3.77	3.62	3.58
	Al+3	0.42	0.27	0.40	0.45	0.51	0.23	0.38	0.42
Octahedral	Al^{+3}	0.63	1.04	0.63	0.49	0.97	1.02	1.14	0.50
	Fe^{+3}	0.63	0.43	0.59	0.56	0.56	0.62	0.50	0.60
	Mg^{+2}	0.97	0.68	1.08	1.31	0.65	0.35	0.29	1.25
	Ti^{+4}	0.05	0.03	0.04	0.05	0.05	0.04	0.05	0.05
Interlayers	Ca^{+2}	0.02	0.01	0.02	0.05	0.02	0.01	0.08	0.03
	Na^{+1}	0.15	0.07	0.08	0.07	0.02	0.12	0.14	0.17
	K^{+1}	0.22	0.22	0.24	0.18	0.27	0.24	0.27	0.09

LOI: Loss of ignition

Table 3. Results of the chemical analyses of the non-monomineralic clay fraction.
Çizelge 3. Monomineralli olmayan kil fraksiyonuna ait kimyasal analiz sonuçları.

Sample No.		KB_1 – 11	KB_1 – 12	KB_1 – 18	KB_1 – 30	KG – 21	KG – 41	KG – 45
Oxides (%)	SiO_2	53.30	55.81	50.13	50.42	50.00	48.28	53.64
	Al_2O_3	18.30	17.37	10.25	11.07	12.14	11.28	10.61
	MgO	8.10	5.05	12.05	11.36	12.26	15.23	13.82
	CaO	0.60	0.15	0.45	0.47	0.00	1.10	0.45
	Fe_2O_3	9.30	9.53	13.19	12.27	12.11	11.29	10.30
	MnO	0.03	0.05	0.07	0.07	0.07	0.08	0.07
	TiO_2	0.68	0.88	1.39	1.21	1.06	1.14	1.06
	Na_2O	0.42	0.57	0.95	1.73	0.00	0.41	0.33
	K_2O	2.97	3.24	1.03	1.33	1.41	0.99	1.52
	P_2O_5	0.00	0.20	0.21	0.20	0.20	0.00	0.15
	LOI	7.02	8.48	9.04	8.28	9.28	7.71	8.13
Total	100.72	101.33	98.76	98.41	98.53	97.51	100,08	
Mineralogy	8S,1I,1C	9S,1I	8S,2(S-C)	8S,1C,1(S-C)	8S,1C,1I	8S,1C,1(S-C)	8S,1I,1C	

(S:Smectite, I:Illite, C:Chlorite, S-C: Smectite-Chlorite, LOI: Loss of ignition)

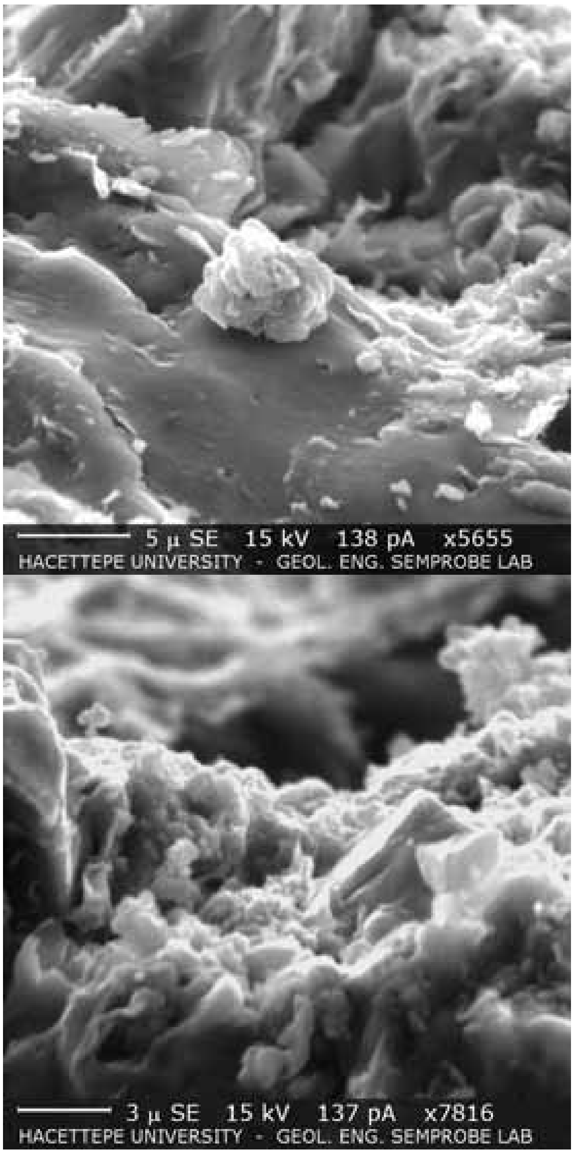

Figure 6. Smectite lamellaes within matrix and feldspars.
Şekil 6. Matriks ve feldispatlar içinde simektit lamelleri.

source area. Similar cases were reported by Bayhan (1981), Bayhan and Yalçın (1990), Yalçın and İnan (1999), Yalçın et al. (1997), İçöz and Türkmenoğlu (1997), and Mongelli (2004). Illites with smaller amounts must have been derived from metamorphic rocks in the source area. Kaolinites were found in Middle Eocene claystones and these were the products of an alteration of feldspars. In these sedimentary levels, the presence of lesser amounts of feldspars, based on whole rock analysis, confirm this opinion. These data suggest that various clay minerals of the sedimentary sequence can be interpreted as indicating the derivation of the sediments from different source rocks in different times to the basin. Similar studies on the Cretaceous-Tertiary boundary were performed by Bozkaya and Yalçın (1991), Martinez-Ruiz et al. (2001), Premovic et al. (2001), and Khormali et al. (2005). Changes in clay minerals and their chemistry can be used to distinguish the Cretaceous-Tertiary transition.

Table 4. Results of the trace element analyses of the clay fraction (ppm).
Çizelge 4. Kil fraksiyonunun iz element sonuçları (ppm).

Sample No.	KB1 – 11	KB1 – 17	KB1 – 42
Ba	217	162	157
Ni	283	704E	575E
Co	32	58	54
Cr	270	933	850
Mineralogy	8S,1C,1I	8CR,1I,1C	8CR,1I,1C

(S:Smectite, CR:Corrensite, I:Illite, C:Chlorite)

CONCLUSIONS

The main conclusions drawn from this study are as follows.

1. Clay mineral assemblages were determined in the Upper Cretaceous-Paleocene-Eocene series where smectite and corensite were determined as the most dominant minerals.
2. According to the results of the chemical analyses, smectites are determined as beidellite and saponite.
3. Saponites and corrensite, have formed from the alteration of detrital material which derived from ultramafic rocks.
4. Beidellites have been formed as a result of the alteration of micas and feldspars of the metamorphic and/or acidic igneous rocks.
5. Illite and kaolinite minerals have probably have derived from the metamorphic and/or igneous rocks in the source area.

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