COMPARISON OF WEATHERING RATES OF THE SOILS CLASSIFIED IN ALFISOL AND ENTISOL ORDER DEVELOPED ON LIMESTONE IN THE TAURUS MOUNTAINS AT EAST MEDITERRANEAN REGION

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Abstract: Entisols and Alfisols are derived from limestone under Mediterranean mountain climate conditions with a mesic temperature regime and a xeric moisture regime. These Entisols are weakly developed, as shown by their reduced thickness and their lack of diagnostic subsurface horizons, The aim of this research is to study and compare the pedogenic evolution of Alfisols and weakly developed Entisols using weathering indices as well as CIA, CIW, WIP, P, PIA, base/R_2O_3, and some geochemical rates together with other features such as the mineralogy and some analytical characteristics. Our results show that soils classified as Alfisol and Entisol have similar weathering indices and pedochemical activity. The major factors determining soil genesis in this area appear to be topographical rather than climatic and the nature of parent material affected by the leaching regime and weathering rates.

Key words: Weathering rates, pedogenic evolution, geochemistry, Alfisol, Entisol

1. INTRODUCTION

Soils show a wide range of variation in terms of time passing 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 under the influence of pedogenic processes determined by vegetation, topography and, in particular, climate. Time passing for soil formation affects the features of soils and the rates of weathering. However, although the time passing for soil formation is the same, the soil morphology and physico-chemical characteristics can vary because of the effects of other soil formation factors.

The mobilization and redistribution of elements during weathering follow various pathways, as different elements are affected differently by the various pedogenic processes, including dissolution of primary minerals, formation of secondary minerals, redox processes, transport of material, and ion exchange (Middleburg et al., 1988). Birkeland (1999) proposed that elements released by weathering may or may not be redistributed down-slope as a function of their mobility under constant or changing geochemical environments along the slope.

Weathering indices for weathering profile samples are conventionally calculated using the molecular proportions of major element oxides. Stoichiometrical changes during weathering are reflected in the index value. The molecular proportion of each oxide is easily calculated from the percentage of the oxide based on weight.

In addition in order to geochemically identify, differentiate, and characterize the degree of rock weathering and investigate the weathering process of soils and sediments, trace elements, especially REE data in the form of chondrite-normalized plots, have been widely used (Taylor & McLennan, 1985; Xing & Dudas, 1993; Land et al., 1999; Price et al 2003; Egli et al., 2003; Egli et al., 2007; Caspari et al, 2006; Buggle et al, 2008; Eppes et al, 2008). The REEs, which are also known as lanthanides, comprise 15 elements with atomic numbers ranging between 57 and 71, i.e. from La to Lu. The resulting REE patterns of soils would appear to be closely controlled by soil weathering (Caspari et al., 2006). Moreover, the REE fractionation and cerium anomalies had been studied

extensively in the weathering environments (e.g. Banfield & Eggleton, 1989; Nesbitt et al., 1980).

Soil formation in mountainous areas is strongly affected by active geomorphic processes (Birkeland, 1999). Where erosion dominates, the majority of soils are formed on fresh colluvial materials or on exposed erosional surfaces (Feldman et al., 1991). Thus, the central image of soils formed in mountains is a weakly developed profile formed on recent sediments (Graham et al., 1988). However, because the time of soil development depends particularly on the slope, aspect, and vegetation of the site, soils in mountainous areas are arranged in a kind of mosaic formed by a combination of slope processes and pedogenesis (Graham et al., 1990). The change in the balance between erosion and weathering is ascribed to climatic change (Birkeland, 1999), land use change (Glade, 2003), or catastrophic events. From another point of view, the zero point for soil formation and geomorphic processes is the same, but the intensity of slope processes varies in space and changes over time. Periodical refreshment of parent material is localized in gullies, areas of landslides, and steep slopes. A slope is generally dynamic, but there are zones of stability where the rate of pedogenesis is higher than the rate of denudation or accumulation, and mature soils do form. Mediterranean Holocene soils are generally weakly developed, the range of different soil maturity stages is limited, and the use of development indices has rarely been discussed. In the Taurus, the soil distribution is Entisol and Inceptisol, as it is in other mountainous areas in the Mediterranean basin (Soil Survey Staff, 1999). Along with these soils, there are also soils of the Alfisol order transitional to each other (Dinç et al., 1999). A significant part of the Entisols in this region are orthents that are mild and sloped (frequently >50%) and spread in areas by severe erosion. Is the reason for the weak development of the mentioned soils – although they exist together with similar old soils in places where Alfisol formation is more intensive – the slow work of pedo-chemical processes, or are the Entisols that came into being in the mountainous areas under the impact of the Mediterranean climate weakly formed soils?

The aim of this study is to carry out a pedological assessment of the soils that are classified as Entisol in the Taurus and the soils in the same region classified as Alfisol to answer the question above and to determine the difference in classification resulting from pedogenic processes or from other factors by determining the degree of weathering of the mentioned soils using geochemical data. Geochemical features along with other features such as the mineralogy and some

analytical characteristics are presented here in order to discuss their use in quantifying the maturity stages and durations of Holocene soil formation.

2. MATERIALS AND METHODS

2.1. Site Description

The study area was situated north of the middle Taurus Mountain zone in central Anatolia, about 120 km west of Konya province, at 36° 44'-37° 23' N latitude and 31° 30'-32° 39' " E longitude. According to the Konya meteorological station, long-term records show that the mean annual precipitation ranges from 468 mm to 764 mm, total evaporation ranges from 975.4-1253 mm, mean annual temperature ranges from 9.7 to 11.6 ºC, and mean annual soil temperature at 50 cm ranges from 12.8 to 14.5 ºC (DMI, 1994). Most precipitation falls in the winter months, with no rain during the summer. Soil moisture and temperature regimes are xeric and mesic, respectively, according to the climate data (Soil Survey Staff, 1999).

The Taurus Mountains are a group of mountain ranges extending from the west, running roughly parallel to the Mediterranean coast, in an arc to the east. The Middle Taurus Mountains form the part of the Taurus Mountains that extends parallel to the Mediterranean coast. The Central Taurus region is formed by several units featuring different stratigraphic, lithologic, tectonic, and metamorphic characteristic but it has mostly limestone formations with various features. The study area is in the Bozkır unit – the Beyşehir–Hoyran Nappes – in Central Taurus; it is an important structural element of the Upper Eocene–Lower Oligocene compressional period. The area is composed of Mesozoic pelagic limestone and green volcanics (Akay & Uysal, 1988).

2.2. Soil Sampling and Analysis

For the study, four widely disturbed soil profiles were chosen, and disturbed and undisturbed soil samples were taken from the horizons after their macromorphological identifications were completed. Soil samples were dried, gently crushed with a wooden roller, and sieved to 2 mm. Visible roots, stubble, and coarse fragments were removed and stored in plastic bags for use. Soil pH was measured potentiometrically both in a 1:2.5 soil/water (w/v) suspension with a glass electrode (Soil Survey Laboratory Methods Manual 2004). Electrical conductivity (EC) was determined potentiometrically in a 1/2.5 soil water suspension using a glass electrode (Soil Survey

Laboratory Methods Manual 2004). Particle size distribution was determined by the hydrometer method after removal of organic matter using H_2O_2 and stirring in a sodium hexametaphosphate solution (Bouyoucous, 1951). Bulk density (BD) was determined by weighing soil cores after drying 24 h at 105 °C (Blake & Hartge, 1986). Organic matter in the soils was determined using the Walkley and Black wet digestion method (Van Lagen, 1993). Cation exchange capacity (CEC) and exchangeable Ca, Mg, K, and Na were extracted using ammonium acetate (1 N, at pH 7) and the quantity determined using a flame photometer and an atomic absorption spectrophotometer (AAS) (Schollemberger & Simon, 1954). The amount of carbonate in the soil was measured using Scheibler calcimeters (Soil Survey Laboratory Methods Manual, 2004). Selective dissolution of Fe was conducted using the dithionite-citrate bicarbonate (DCB) method, and their amounts were measured by AAS (Soil Survey Laboratory Methods Manual, 2004). Cation was designated by subscript d. The total element analysis of the soil and rock samples was conducted by the fusion with Lithium metaborate ($LiBO_2$) and dilution in HNO_3-HF (Chao & Sanzolone, 1992), and the contents were measured using inductively coupled argon plasma (ICP). All procedures were replicated three times for each soil, and the means were reported. Loss on Ignition (LOI) was determined from the weight loss after roasting the samples at 1050°C for 2 h. XRD analysis was also performed on powdered samples with randomly oriented powder mounts by Shimadzu XRD-6000 with a Cu anticathode and K filter (40 kV, 35 mA). Diffractometric analysis of the pulverized saprolite and rock samples was carried out in the 2 to 40 $^o2\theta$ range (Jackson, 1979). The clay fraction (<2 μm) was obtained from the soil after destruction of organic matter with dilute and Na-acetate buffered H_2O_2 (pH 5) by dispersion with calgon and sedimentation in water. Oriented specimens on glass slides were analyzed by X-ray diffraction using Cu-Kα radiation from 2 to 15 °2θ with steps of 0.02 °2θ at 2 s per step. The following treatments were performed: Mg saturation, ethylene glycol solvation (EG), and K saturation, followed by heating for 2 h at 550 °C. Minerals and relative abundance were identified by their diagnostic XRD spacing and evaluated by their XRD relative peak intensities in the XRD diagram.

2.3. Calculation of Weathering Indices

Several indexes have been defined to characterize chemical weathering in soils (e.g.

Hornois 1988; Nesbit & Young, 1989). The general principle of all these indexes is similar and based on the ratio of the base cations (CA, Mg, K, Na) to Al and Si. We used the weathering indices for the quantification of chemical weathering intensity in this study such as Chemical Index of Alteration (CIA) (Nesbitt & Young 1982), Chemical Index of Weathering (CIW) (Harnois, 1988), Bases/R_2O_3 Ratio (Birkeland, 1999), Weathering Index of Parker (WIP), (Parker, 1970), Plagioclase Index of Alteration (Fedo et al., 1995) and Product Index (P) (Reiche, 1943). In the equations, CaO* is associated with the silicate fraction and corrected for inputs from carbonate and apatite. We estimated the amount of carbonate in the soil by assuming that all measured inorganic carbon was in the form of calcite, assuming an average CaO ratio of 56% (Çelik & Karakaya, 1998) and calculating the amount of Ca associated with the inorganic carbon. CaO* is based on the assumption that the molar CaO/Na_2O ratio of silicates is not higher than one. In the case that the molar CaO content (corrected for apatite) is less than the molar Na_2O content, this value was taken as CaO*. In the other cases, the CaO content of silicates was assumed to be equivalent to the molar Na_2O content (McLennan et al, 1993). In this study, apatite ($Ca_5(PO_4)_3$) correction was also made by assuming that all measured P_2O_5 was from apatite and calculating the amount of Ca associated with it.

3. RESULTS

3.1. Morphological Properties

A description of the study sites and four respective representative soil profiles are reported in table 1. The profiles were classified as Lithic Xerorthent (P2, P4), Mollic Haploxeralf (P1), and Lithic Haploxeralf (P3) (Soil Survey Staff, 1999) (Table 1). All profiles occur on limestone at an elevation of 1397-1788 m, with a slope gradient of 20-60%, under 550-900 mm precipitation and forest vegetation. Horizon differentiation was poor in profiles 2 and 4. The soils of profile 2 and 4 have a horizon sequence A–C–R and Ah–A–C, and they are shallow (about 22 cm), skeletal, and clay and sandy loam. The soils have a horizon sequence A–Bt–R and A–Bt–C (P1 and P3) and are shallow (about 83 cm) and clayey. The solum thickness ranged from 15 to 83 cm.

The profiles studied were well-drained. From the profile description, it is apparent that distinct soil horizons are lacking, with the exception of a weakly defined A (in profiles 2 and 4), but an argillic horizon was found (in profiles 1 and 3).

Table 1. Morphological properties of profiles

Pedon	Horizon	Depth (cm)	Color dry	Color moisture	[a]Structure	Boundary	Classification
I	A1	0-14	10R 3/3	10R 2/2	mo, f, gr	gradual, smooth	Mollic Haploxeralf
	A2	14-26	10R 3/4	10R 3/3	st, f, ab	clear, smooth	
	Bt1	26-52	2,5YR4/6	2,5YR3/4	st, me, ab	clear, smooth	
	Bt2	52-83	2,5YR4/8	2,5YR4/6	st, me, ab	clear, irregular	
	R	+83	-	-	-	-	
II	Ah	3-0	7,5YR3/2	7,5YR2/1	mas	gradual smooth	Lithic Xereorthent
	A1	0-8	5YR4/8	5YR3/6	st, me, gr	gradual smooth	
	A2	8-39	2,5YR4/6	5YR4/8	st, co, gr	gradual smooth	
	C	+39			-	-	
III	A1	0-7	5YR4/6	5YR3/4	w, me, gr	clear, smooth	Lithic Haploxeralf
	A2	7-16	5YR3/6	5YR3/4	st, me, gr	abrupt, smooth	
	Bt1	16-29	2,5YR4/6	2,5YR4/4	st, me, ab	gradual smooth	
	Bt2	29-45	2,5YR4/4	2,5YR3/4	st, me, ab	clear, irregular	
	C	+45	-	-	-	-	
IV	A1	0-8	2,5YR4/6	2,5YR4/6	mo, f, gr	gradual, broken	Lithic Xereorthent
	A2	8-22	2,5YR5/6	2,5YR3/4	st, f, ab	gradual, broken	
	R	+22	-	-	-	-	

[a] Structure; w: weak; mo: moderate; st: strong; me: medium; f: fine; co: coarse; mas: massive; gr: granüler; ab angular blocky

In addition, profile 1 has a mollic horizon. The soil morphology consisted of A horizons of 08–39 cm. Continuous C and R horizons were present under A layers in profiles 2 and 4. An argillic B horizon lay under the A horizon in profiles 1 and 3. All had slightly to moderately developed granular A horizons. Profiles 1 and 3 had moderately to strongly develop angular blocky structure in the B horizons. The soil structure was massive in the C layers in all profiles. In general, the upper mineral horizons were characterized by high organic carbon content (2.7%–6.9%). The color hue varied from 2.5 YR to 10 R and was characterized by higher values in deeper layers. The surface horizons of all pedons showed a dark reddish brown to dull reddish brown color, with subsurface horizons showing dull reddish brown to reddish brown color. Profiles 1, 2, and 3 were characterized by a fine texture, while profile 4 was characterized by a coarse texture in the surface horizon.

3.2. Physical, chemical and Mineralogical Properties

The main physical and chemical properties of the four profiles are presented in tables 2 and 3. The bulk density (BD) values of the soils ranged from 1.01 to 1.76 g·cm^{-3}, with surface soils generally having lower BD values than subsurface soils. The lower BD values of the surface soils were attributed to the relatively higher organic C content of the surface soils. All soils followed the general trend of having the highest organic matter content at the surface. The organic matter content ranged from 0.7% to 6.9% and declined rapidly with depth. Soil pH$_{(H2O)}$ values ranged from 6.84 to 8.06, with no regular distribution. CEC values ranged from 23.8 to 42.3 cmolc·kg^{-1} and showed no trend with depth. CEC values correlated with organic matter and clay fraction content. The base saturation values ranged between 87% and 100%. The texture of the soils was clayey sandy and sandy loamy clay (profile 4). The sand content ranged from 2.8% to 25.2%, silt content from 12.8% to 53.3%, and clay from 37.6% to 76%. Profiles 1 and 3 had high sand content, but the clay concentrations generally increased with depth. The CaCO$_3$ content ranged from to 1.3% to 32.6%. Sodium dithionite citrate (DCB) extracts affected crystallized materials more than the other extracts. In the studied profiles, free Fe ranged from 1.24% to 4.19% and showed no trend with depth.

According to X-ray diffractograms (Fig. 1) of selected samples, no distinct differences in clay mineral distribution with depth were observed, and pedons from all geomorphic surfaces had similar mineral components. In the clay fraction, three intense peaks with weak and dirty signals were observed. The Mg-saturated clay exhibited three intense peaks at 1.4–1.5 nm, 1.0 nm, and 0.72–0.73 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 about 1.6–1.7 nm, and the same peak closed to 1.4–1.2 nm after K saturation at 20 °C, but at 550 °C, an ill-defined diffraction band between 1.0 and 1.1 nm was observed, indicating the presence of chlorite-smectite interstratified with smectite, illite, and kaolinite.

The most abundant clay mineral is kaolinite, followed by illite and chlorite-smectite interstratified with smectite. X-ray diffraction (XRD) patterns of whole soils indicated the presence of calcite, dolomite quartz, feldspars (microcline-orthoclase), biotite, plagioclases (anortit), olivine (Forsterit), hornblende, and hematite.

Table 2. Some Physical and Chemical Properties of Studied Soils Soils

Pedon	Horizon	Depth (cm)	pH(H2O) 1/2,5	EC (μS.cm^{-1})	CaCO$_3$ (%)	Organic matter (%)	CEC (cmolc·kg^{-1})	Bulk Density (gr.cm^{-3})	Base Saturation (%)	Fe$_d$ (%)	Particle Size Distribution (%)			Texture class
											Sand	Clay	Silt	
I	A1	0-14	6.84	146	1.3	6.1	37.7	1.33	95	3.54	25.2	50.8	24.0	C
	A2	14-26	7.20	78	1.8	3.4	34.7	1.35	95	3.72	20.6	56.6	22.8	C
	Bt1	26-52	7.27	129	1.3	2.3	40.3	1.59	94	3.96	19.2	68.0	12.8	C
	Bt2	52-83	7.57	138	3.4	0.7	37.1	1.64	100	4.19	7.0	76.5	16.5	C
	R	+83	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
II	Ah	3-0	7.25	207	2.6	6.9	42.3	1.01	100	2.57	4.9	56.6	38.5	C
	A1	0-8	7.44	118	2.7	6.1	35.2	.1.43	100	2.88	4.2	70.8	25.0	C
	A2	8-39	7.50	153	3.0	3.8	35.9	1.66	90	2.71	2.8	71.9	25.3	C
	C	+39	-	-	-	-	-	-	-	-	-	-	-	-
III	A1	0-7	8.03	151	28.8	4.7	32.9	1.40	100	1.32	19.1	47.4	33.5	C
	A2	7-16	7.78	182	28.1	4.1	33.9	1.47	100	1.35	18.9	49.0	32.1	C
	Bt1	16-29	7.88	145	29.9	2.1	23.8	1.70	100	1.43	16.3	54.7	29.0	C
	Bt2	29-45	8.06	146	32.6	0.9	24.7	1.76	100	1.24	15.3	55.8	28.9	C
	C	+45	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
IV	A1	0-8	7.78	147	4.2	2.7	29.8	1.50	100	2.60	9.1	37.6	53.3	SCL
	A2	8-22	7.75	152	2.9	1.8	32.7	1.58	87	2.78	3.3	60.4	36.3	C
	R	+22	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table 3. Some Major and minor element concentrations of the studied profiles

Pedon	Horizon	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	MgO	CaO	Na$_2$O	K$_2$O	TiO$_2$	P$_2$O$_5$	Ba	Co	Cs	Nb	Rb	Sr	LOI	Total
I	A1	37.39	7.05	16.87	16.80	1.37	0.26	0.66	0.43	0.10	137.2	210.6	2.5	9.0	33.5	62.2	16.8	99.94
	A2	38.31	8.73	19.49	13.85	0.92	0.20	0.81	0.48	0.10	148.2	195.5	3.8	10.4	42.8	53.8	15.4	99.95
	Bt1	39.45	10.24	17.60	13.26	0.98	0.15	0.90	0.50	0.08	149.9	148.7	6.5	11.0	49.7	58.3	15.3	99.83
	Bt2	41.95	16.42	17.26	4.49	1.18	0.15	1.29	0.80	0.12	199.3	127.2	11.8	17.6	71.6	67.5	15.0	99.83
	R	0.06	<0.03	<0.04	0.35	55.73	0.01	<0.04	<0.01	0.02	2.6	<0.5	<0.1	<0.5	<0.5	225.1	43.8	100.02
II	Ah	44.56	16.65	7.91	1.61	1.84	0.36	2.1	0.9	0.27	344.4	24.2	14.5	20.7	105.8	126.9	23.5	99.91
	A1	47.81	19.38	9.35	1.7	1.37	0.27	2.24	0.96	0.21	349.9	28.6	17.6	25.2	118.9	140.8	16.4	99.90
	A2	48.18	19.67	9.82	1.61	1.32	0.19	2.03	0.96	0.22	338.6	30.0	19.8	24.3	110.7	133.1	15.7	99.90
	C	0.41	0.07	<0.04	0.38	55.79	0.02	<0.04	<0.01	0.03	14.8	<0.5	0.2	<0.5	0.6	347.6	43.2	99.93
III	A1	36.86	10.01	4.07	1.39	19.20	0.09	1.27	0.51	0.09	215.7	10.3	4.8	10.8	69.2	170.7	26.4	99.97
	A2	38.5	10.02	4.16	1.32	18.99	0.08	1.25	0.51	0.08	229.4	11.6	4.7	10.9	73.4	170.5	25	99.99
	Bt1	39.86	11.06	4.57	1.33	18.27	0.07	1.27	0.55	0.04	217.9	10.8	4.9	11.4	73.8	146.7	22.9	100.01
	Bt2	39.14	11.03	4.57	1.32	19.13	0.06	1.25	0.54	0.05	239.6	11.3	5.3	11.5	76.5	161.9	22.8	99.97
	C	2.08	0.64	0.20	0.44	53.61	0.01	0.07	0.03	0.01	26.0	0.5	0.3	0.7	4.6	227.5	42.9	100.00
IV	A1	46.87	17.4	7.96	1.71	5.39	0.36	2.39	0.99	0.23	457.5	21.9	9.3	25.2	117.6	137.9	16.4	99.91
	A2	49.80	20.56	9.48	1.55	1.35	0.26	2.9	1.1	0.14	466.9	25.4	14.4	27.7	144.0	116.0	12.6	99.92
	R	0.41	0.21	0.25	0.30	55.82	0.01	0.05	0.01	0.03	34.8	<0.5	0.1	<0.5	2.2	216.0	42.9	100.01

Si, Al, Fe, Mg, Ca, Na, K, Ti, P, LOI, values in %, other values in ppm, LOI: Loss on Ignition

Table 3. Continue

Pedon	Horizon	Th	U	Zr	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
I	A1	5.0	1.7	79.0	19.1	42.2	4.23	15.5	3.1	0.69	2.68	0.50	2.54	0.58	1.79	0.27	1.69	0.24
	A2	4.9	1.9	85.2	23.5	47.1	4.92	18.8	3.8	0.84	3.29	0.54	2.83	0.62	1.80	0.27	1.55	0.24
	Bt1	7.3	1.8	93.0	27.4	53.4	5.89	23.0	4.2	0.91	4.02	0.63	3.38	0.77	2.21	0.34	1.85	0.29
	Bt2	11.1	2.0	144.2	46.3	82.8	9.41	36.0	7.0	1.57	6.51	0.98	5.83	1.27	3.66	0.55	3.46	0.49
	R	0.1	0.2	<0.5	<0.5	<0.5	0.04	<0.4	<0.1	<0.05	<0.05	0.02	0.09	<0.05	0.06	<0.05	0.07	0.01
II	Oa	13.3	3.1	201.4	48.6	98.9	10.45	37.7	7.9	1.72	6.90	1.06	6.09	1.26	3.71	0.55	3.44	0.53
	A1	15.5	3.7	216.5	58.5	113.6	12.42	48.2	9.4	2.06	8.58	1.38	7.68	1.60	4.56	0.71	4.37	0.63
	A2	14.7	3.8	208.7	61.8	114.2	13.25	50.7	9.6	2.18	9.02	1.45	8.07	1.74	5.01	0.75	4.46	0.69
	C	0.3	1.0	0.9	2.7	1.2	0.40	1.4	0.3	0.08	0.47	0.05	0.39	0.09	0.26	<0.05	0.12	0.01
III	A1	7.2	1.9	123.9	28.8	63.1	6.78	24.7	4.8	1.02	4.33	0.69	3.86	0.82	2.18	0.34	1.93	0.32
	A2	8.5	2.0	127.6	29.3	63.7	6.66	25.2	4.9	1.04	4.39	0.72	3.76	0.80	2.37	0.37	2.36	0.27
	Bt1	9.8	2.1	125.0	28.5	61.6	6.57	25.5	5.1	1.00	4.25	0.72	3.75	0.78	2.24	0.36	2.11	0.29
	Bt2	8.8	2.1	130.6	29.1	61.8	6.41	24.4	4.7	1.04	4.24	0.69	4.12	0.85	2.32	0.35	2.07	0.31
	C	0.6	3.4	6.3	1.8	3.6	0.44	1.5	0.3	<0.05	0.31	0.04	0.29	<0.05	0.15	<0.05	0.12	0.01
IV	A1	16.9	3.5	243.1	56.7	125.1	12.39	44.9	8.7	1.91	7.39	1.26	7.07	1.45	4.19	0.61	3.76	0.56
	A2	17.9	4.7	262.8	64.3	135.1	14.22	51.9	10.6	2.32	8.70	1.52	8.44	1.66	4.84	0.76	4.55	0.71
	R	0.2	0.6	2.5	0.9	1.6	0.17	0.6	<0.1	<0.05	0.08	0.01	0.12	<0.05	0.06	<0.05	0.07	<0.01

Table 4. Weathering rates of studied soils.

Pedon	Horizon	CIA	CIW	Base/R$_2$O$_3$	WIP	P	PIA
I	A1	81.77	89.18	2.42	2546	77.60	73.46
	A2	85.03	92.99	1.69	2303	74.95	76.47
	Bt1	87.45	95.40	1.60	2281	75.22	79.11
	Bt2	89.66	97.08	0.47	1619	71.49	82.02
	R	nd	nd	nd	nd	nd	nd
II	Oa	82.78	93.36	0.33	2068	76.83	71.45
	A1	85.38	95.62	0.29	2138	75.37	74.67
	A2	87.43	96.92	0.26	1914	75.10	77.64
	C	nd	nd	nd	nd	nd	nd
III	A1	85.67	97.13	0.39	1271	82.54	73.88
	A2	86.09	97.44	0.37	1241	83.09	74.43
	Bt1	87.30	97.96	0.34	1250	82.20	76.43
	Bt2	87.65	98.24	0.34	1230	81.97	76.87
	C	nd	nd	nd	nd	nd	nd
IV	A1	82.16	93.63	0.34	2321	77.05	69.92
	A2	83.71	96.01	0.28	2644	75.14	70.89
	R	nd	nd	nd	nd	nd	nd

Weathering indices were calculated using oxides in molecular proportions, nd: not determined

3.3. Weathering Indices and Anomalies

Indices of alteration calculated from elemental oxide concentration in molecular proportion were used to evaluate the weathering degree of the soils classified in different soil orders (Alfisol and Entisol). Some weathering rates, shown in Table 4, were obtained from the geochemical features of the soils in the study, and some genetic rates and Eu and Ce anomalies are shown in table 5.

In the profiles, the CIA rate varied between 81.77 and 89.77, and no significant differences were found between the profiles. The highest CIA value was in the Bt2 horizon of profile 1, and the lowest value was, again, in profile 1 and in the A1 horizon. The CIA values increased with depth in all profiles. The variation in CIW values between profiles was also limited. The CIW values ranged between 89.18 and 98.24 and tended to increase with depth.
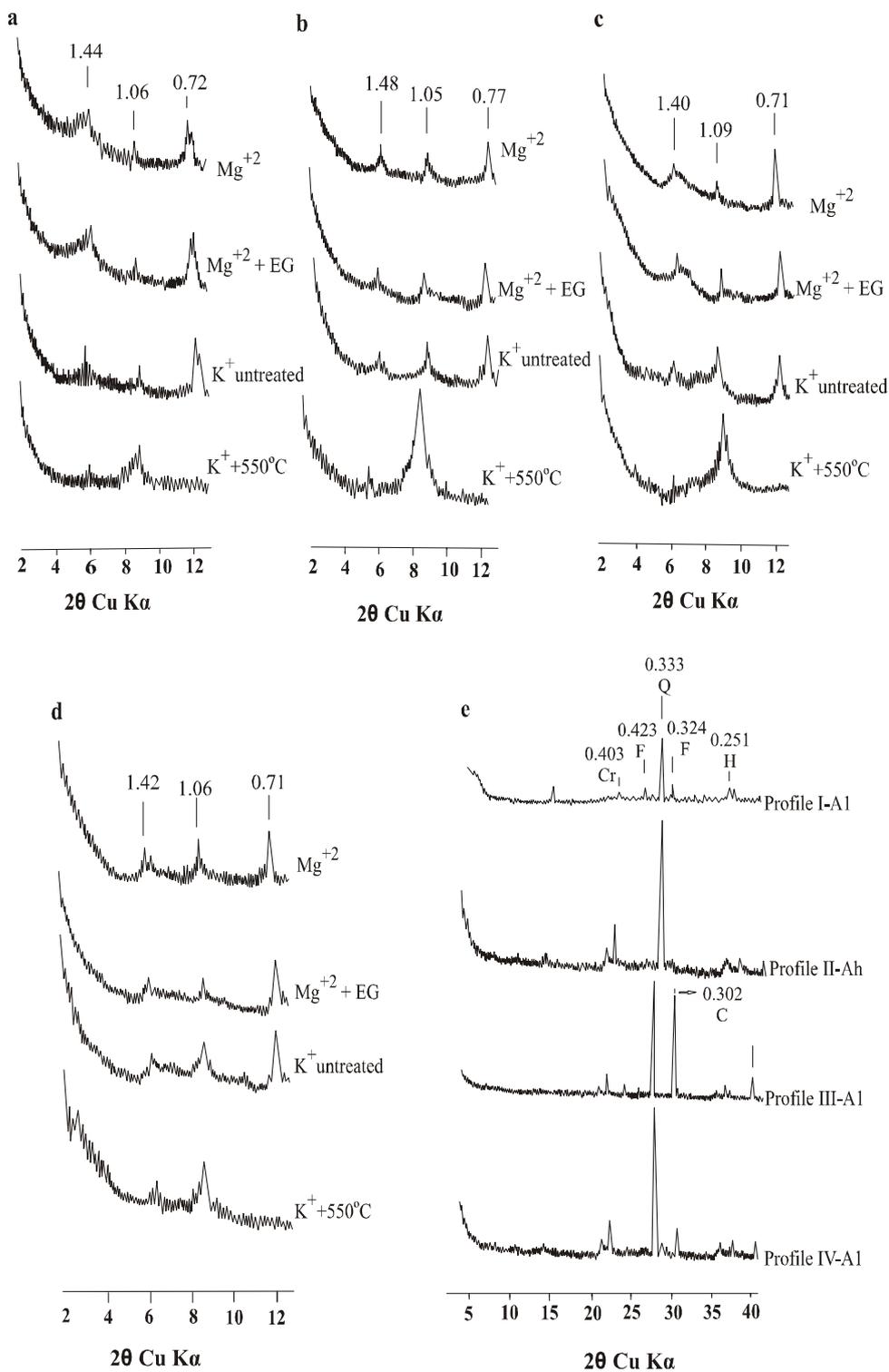
Figure 1. X-ray diffractograms of selected samples: (a)P1-A1; (b) P2-Ah; (c) P3-A1; (d)P4 A1 (Clay minerals);
(e) Primer minerals; (F) Feldspar; (Q) Quartz; (H) hematite; (Cr) Cristoballite; (C) Calcite; *d*-values in nm

The bases/R_2O_3 value was below 1 in all profiles except for profile 1, ranging between 0.26 and 2.42. The WIP index was distributed between 1229 and 2644. The P index varied between 71.49 and 83.09. While it tended to decrease with depth in profiles 2 and 4, no regular change trend in profiles 1 and 3 was observed. The PIA value showed a similar variation in profiles and ranged between 69.92 and 82.02. In all profiles, it tended to increase with depth. Among the geochemical rates calculated to determine weathering and enrichment-depletion rates, the Th/U value ranged between 0.69 and 2.17.

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Table 5. Some genetic ratios and Eu and Ce anomalies of studied soils.

Pedon	Horizon	Th/U	Ba/Nb	Ti/Nb	Zr/Rb	La/Lu	La/Yb	La/Sm	Rb/Sr	Er/Ho	(Rb+Zr)/Sr	Ce/Ce*	Eu/Eu*
I	A1	1.31	2.25	0.26	0.49	7.96	7.31	3.53	3.01	1.20	3.01	1.05	0.74
	A2	1.49	2.10	0.25	0.42	9.79	9.81	3.55	4.44	1.13	4.44	0.98	0.73
	Bt1	0.95	2.01	0.25	0.39	9.45	9.58	3.74	4.76	1.12	4.76	0.94	0.68
	Bt2	0.69	1.67	0.25	0.42	9.45	8.66	3.79	5.92	1.12	5.92	0.88	0.72
	R	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
II	A	2.17	3.44	0.22	0.27	10.91	10.28	3.91	0.89	1.15	0.89	1.00	0.71
	C	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	R	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
III	Oa	0.90	2.45	0.24	0.40	9.17	9.14	3.53	4.66	1.15	4.66	0.98	0.72
	A1	0.92	2.05	0.21	0.38	9.29	8.66	3.57	4.72	1.11	4.72	0.94	0.71
	A2	0.99	2.05	0.22	0.39	8.96	8.97	3.69	4.65	1.12	4.65	0.89	0.72
	C	nd	nd	nd	nd	Nd	nd	nd	nd	nd	nd	nd	nd
IV	A1	1.01	2.94	0.26	0.37	9.00	9.66	3.44	2.26	1.04	2.26	1.01	0.69
	A2	0.90	3.10	0.26	0.36	10.85	8.03	3.43	2.40	1.16	2.40	1.02	0.69
	Bt1	0.82	2.82	0.27	0.35	9.83	8.74	3.21	2.81	1.12	2.81	1.00	0.66
	Bt2	0.92	3.07	0.26	0.36	9.39	9.10	3.55	2.64	1.06	2.64	1.01	0.72
	C	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
V	A1	0.80	2.68	0.22	0.43	10.13	9.76	3.74	4.76	1.13	4.76	1.05	0.73
	A2	1.01	2.48	0.22	0.38	9.06	9.14	3.48	6.93	1.14	6.93	1.00	0.75
	R	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

nd: not determined

The lowest value was seen in profile 1 in horizon Bt2. Ba/Nb was distributed between 1.67 and 3.10. It generally tended to decrease with depth. Ba/Sr ranged between 3.49 and 11.12. Sr made substation in spite of Ca in CaCO3; the variation interval in the profiles in terms of limestone content was large. A similar situation was also seen in the variations in Rb/Sr and (Rb+Zr)/Sr values. As for Rb/Sr 2.26-6.93 and (Rb+Zr)/Sr, the variation was between 2.26 and 5.92. In the rates obtained using Ti and Zr, which are also used as index elements in the digitization of weathering levels of the soils, showed homogenous values. Ti/Nb ranged between 0.21 and 0.27, and Zr/R ranged between 0.35 and 0.49. The La/Lu rate is an important indicator used in weathering and provenance studies in soils. This value did not show significant variation in profiles classified in different orders and ranged between 7.96 and 10.85. Generally, the values were clustered around 9. In Er/Ho, which shows great variation in soils with weathering, ranged from 1.04 to 1.20. The change curve of the La/Nb and Ls/Sm values between soils, an important indicator of LREE, HREE enrichment, and, in turn, clay movement in soils, had quite a similar distribution trend. These rates ranged between 7.31-9.81 and 3.21-3.79, respectively. Ce and Eu anomalies, indicators of weathering and oxidation conditions in soils, showed a homogenous distribution, and no any significant differentiations were found between values. While negative Eu anomalies were found in the soils, a weak positive Ce anomaly was found in profiles 3 and 4. In the soils studied, the Eu and Ce anomalies ranged between 0.66-0.75 and 0.88-1.05, respectively.

4. DISCUSSION

The mean annual precipitation is 550-600 mm in profile 1. This value is 600-650 mm, 650-700 mm, and 600-750 mm in profiles 2, 3, and 4, respectively. The studied soils were situated on a steep slope. The weak development of the soils in the Taurus Mountains (also including the Entisols and Inceptisols as a soil typology, which are very abundant in this region) has traditionally been attributed to two main factors: the relief, since the soils are found on moderate or steep slopes where the rate of erosion exceeds the rate of formation of pedogenic horizons; and the climate, which is a Mediterranean mountain type with low temperatures decreasing with altitude and moderate precipitation increasing with altitude. Under these conditions, it is supposed that weathering is principally physical, by fragmentation (Delgado et al., 1987). All profiles have similar mineralogical properties.

The CIA is based on the progressive removal of soluble cations (e.g. Ca, Na, and K) from minerals during chemical weathering and reflects the proportion of primary and secondary minerals in the bulk sample. CIA represents the degree of alteration of feldspars to clay minerals in the course of hydrolytic weathering and indicates the relative content of clay minerals. 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). The studied soils have CIA values of 85-90. When CIA values are classified as little weathered (50-60), a little weathered (60-70), moderately weathered (70-80), highly weathered (80-90), and extremely weathered (90-100), it is seen that although all of the soils in the study field are classified into different orders, they are all in the same class. As the change interval of CIA values between profiles is limited and in spite of some differences in the horizon array in these soils, which are in the same class and exposed to similar weathering processes, there occurred variations in the profile differentiations because of other factors. The CIW value ranged from 50 to 100 in soil from unweathered rock to intensively weathered rock and increased with weathering. The CIW displayed similar behavior for the profiles in this study. For both orders, the CIW values ranged between 90 and 100. If the classification for CIA is done for CIW as well, it is seen that both profile 1 and 3, classified as Alfisol, and profiles 2 and 4, classified as Entisol, are in the same class in terms of CIW values. It provides further evidence of the fact that these soils which have different morphologies in fact similar weathering processes. Another index used to evaluate weathering degree is the Parker weathering index (WIP). WIP decreases with weathering. Profile 1, classified as Alfisol, and profiles 2 and 4, classified as Entisol, show similar behaviors in terms of WIP. However, the WIP values in profile 3, also classified as Alfisol, ranged between 1230 and 1271, showing great weathering. The WIP value, which showed close values for profiles in the Entisol order, showed significant differences in the profiles classified as Alfisol. Though the use of the index in the soils in the study field seems to be problematic, the WIP values did not show grouping according to taxonomic classes. This shows that the profiles' taxonomic classes do not reflect weathering levels. The bases/R_2O_3 ratios ranged from 0 to 10 in soils and decreased with weathering. In profiles 2, 3, and 4, these values are close to each other, and the orders did not show a clustering. The higher values in profile 1, especially in surface horizons, are probably due to the fact that this profile is the one with the least rainfall, thus resulting in less leaching of bases. PIA is used as an alternative index to CIA to quantify the weathering degree and for succeeding plagioclase alteration. In all profiles studied, the values for this index were found to be very close to each other regardless of taxonomic class. A similar trend was seen in the distribution of product index (P) values. In soils, the P values decreased with weathering. The P values were close to each other in profiles in different orders,

indicating similar weathering conditions.

Another way to study the degree of chemical weathering of the investigated soil profiles is to calculate the relative change of REE concentration. The abundance of trace elements and REEs in sediments has been employed to provide clues as to both sources and changes in sediments from weathering and sedimentary processes (e.g., Taylor & McLennan, 1985). Some geochemical ratios were used to quantification of weathering degree of studied profiles. The trace elements and REEs of the studied soils normalized to chondrite (Wood et al, 1979) are shown in figure 2. Normalized REE patterns can reflect the degree of weathering of materials, and this also applies to a lesser extent to the LREE fraction. Ce and Eu can occur in different oxidation states and often show greater fractionation relative to the other REEs. The REE concentrations are normalized relative to a chondritic reference standard to facilitate the comparison of REE patterns between sites. Europium anomalies are estimated by comparing the measured concentration of Eu with an expected concentration of Eu* obtained by interpolation between the normalized values of Sm and Gd, as proposed by Taylor & McLennan (1985):

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

In all profiles, Eu anomalies were negative and very close to each other. The similarity of the negative Eu anomalies and their values in profiles classified in different orders indicate the existence of low and similar weathering conditions. Fractionation of Ce is known to occur during weathering and sedimentary processes. In the initial stages, negative Ce anomalies are seen in weathering products such as secondary hydrous phosphates (Braun et al., 1998), and positive Ce anomalies appear in intensely weathered lateritic profiles where soluble Ce^{3+} oxidizes to insoluble, thermodynamically stable Ce^{4+} and accumulates in secondary cerianite, $Ce(IV)O_2$ (Pan & Stauffer, 2000).

Cerium anomalies are estimated by comparing the measured concentration of Ce with an expected concentration of Ce* obtained by interpolation between the normalized values of La and Pr:

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

Like Eu/Eu*, Ce anomalies showed small differentiation between profiles. The homogenous and relatively small Ce anomaly of the studied soil samples (0.88<Ce/Ce*<1.05; Table 4) indicated that the chemical weathering they underwent was similar and not intensive. Another indicator of weathering in soils is the enrichment of heavy (HREE) or light earth elements (LREE). LREE is closely related with clay amount and movement. LREE is largely kept in the clays. Concordantly, the $La_{(N)}/Yb_{(N)}$ values, which are indicators of LREE/HREE, were examined.
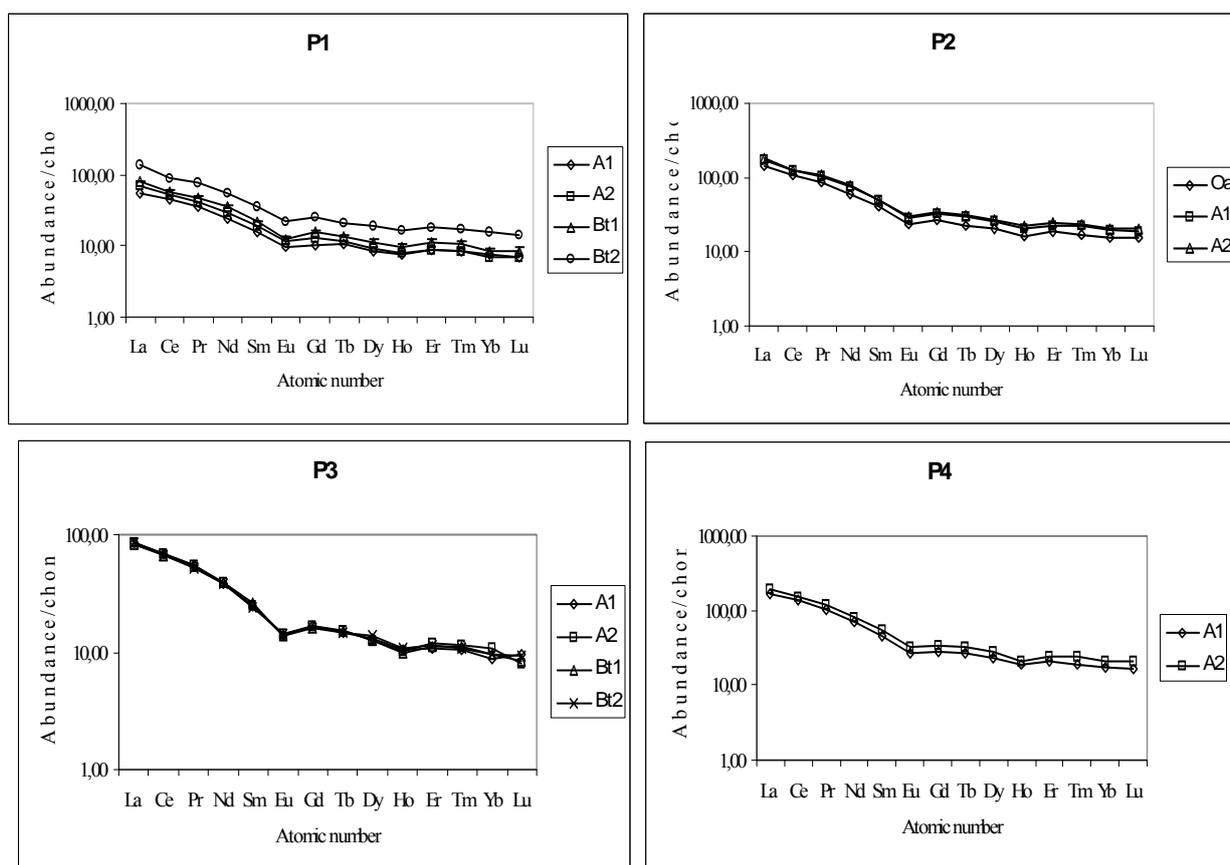
Figure 2. Spider diagrams of chondrite normalized values of REE of the studied soils.

In all profiles, the $La_{(N)}/Yb_{(N)}$ rates were very close to each other, showing a positive distribution in all of them. This homogenous distribution among profiles indicates that LREE is similar in profiles and, thus, that they were exposed to similar leaching effects. On the other hand, the distribution of the $LA_{(N)}/Sm_{(N)}$ rate is very homogenous, which is an indicator of middle rare earth elements. This case indicates that although profiles are classified in different orders, their weathering levels are similar. Sr is an element that is very strongly fixed by clays, and $Rb_{(N)}/Sr_{(N)}$ rate is a useful parameter in the determination of clay sedimentation.

In the profiles studied, the distribution of $Rb_{(N)}/Sr_{(N)}$ values among them is very uniform. The facts that the $Rb_{(N)}/Sr_{(N)}$ rate was positive in all profiles, did not show a homogenous distribution among profiles, and showed an increase with depth indicate that weathering is not intensive and that the severity of weathering is similar. Only in profile 3 this value lower than the others. The reason for this is not that weathering was more intense in this profile but probably results from the substation of Sr in spite of Ca in $CaCO_3$, which is commonly found in this profile. Thus, the mobility of Sr is limited and lower amounts are obtained. Weathering trends can also be demonstrated in a plot of Th against Th/U. With the

enhancement of weathering intensity, the Th/U ratios in weathering products increase above the upper crustal igneous values of 3.5 to 4.0 (McLennan et al., 1993). The Th/U showed a flat differentiation in studied profiles. The Th/U ratios ranged from 0.8 to 1.0 in soils classified both as the Alfisol order and the Entisol order. This slight differentiation in Th /U ratios indicates similar weathering conditions in profiles. Ba^{+1} is an element with ionic potential lower than 3 that can be leached easily in soils. However, Nb has a high ionic potential (>3), and its mobility in the soil is very limited.

Ba/Nb is an indicator that can be used in the quantification of weathering levels of soils, and as the rate of weathering increases, the Ba/Nb rate decreases. In the profiles studied, the variation in Ba/Nb rate among profiles was quite limited; similar values were obtained. This indicates the existence of similar weathering conditions, although the profiles were classified into different orders. La/Lu values were also used in the quantification of weathering as an indicator of clay sedimentation in soils. The homogenous distribution of La/Lu values and the differentiation between horizons without a regularly increasing trend indicates that weathering intensity is similar, too. Ti and Zr are often considered to be almost immobile. To better estimate elemental gain and loss from

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weathering and to calculate the mass balance relative mobility of other elements and soil discontinuities, immobile index elements such as Ti or Zr are often used, as along with the elemental concentration ratio of saprolite and parent bedrock due to potential volume change during soil formation (Kabata-Pendias & Pendias 1992; White, 1995). In the profiles studied, some rates were examined to quantify weathering by using Ti and Zr. In the profiles, Ti/Nb and Zr/Rb showed a very narrow variation interval, indicating similar weathering intensity. Similarly, although (Rb+Zr)/Sr was classified in different orders, it showed a quite homogenous distribution among profiles. The fact that this value was lower in profile 3 compared to the others results from the substation of Sr in $CaCO_3$ in spite of Ca and, thus, its mobility was limited. Ho would have more easily been lost due to leaching, resulting in an increase in the Er/Ho ratio in weathered profiles. The Er/Ho ratio ranged from 1.04 to 1.20 in the studied profiles, showing similar weathering rates among the profiles. Furthermore, the pedogenic activity is also shown by the mineralogical composition through the presence of both transformed minerals (interstratified chlorite–smectite) and of neoformed minerals (kaolinite, hematite, and lower quantities of smectite), which were similar in all profiles. The similarity of the clay and primary minerals in the profiles and the limited variation in the type and amount of minerals and similar physico-chemical properties also indicate similar weathering conditions.

5. CONCLUSIONS

Features of pedogenic evolution were detected in mountain soils classified as Orthent (Entisols) and Xeralf (Alfisols) from the Middle Taurus Mountains (Southern Turkey). For these purpose geochemical features, some physico-chemical and mineralogical properties were determined to compare the weathering rates of profiles. The weathering indices as well as CIA, CIW, WIP, P, PIA, base/R_2O_3, some geochemical rates, and other characteristics (mineralogical, chemical, etc.) indicated some pedogenic evolution. These findings indicate that soils classified as Alfisol and Entisol have similar pedochemical activity. Although the soils had similar weathering rates, they were classified in different orders as a result of erosion, which occurs with a high slope. The major factors determining soil genesis, classification, morphological properties, and account of diagnostics horizons in this area appear to be the result of the topography causing erosion rather than climate and the nature of parent material affected by leaching regime and weathering rates.

REFERENCES

Akay, E. & Uysal. Ş., 1988. *Post-Eocene tectonics of the central Taurus Mountains.* Mineral Research Exploration Bulletin, 108, 23-34

Banfield, J.F. & Eggleton, R.A., 1989. *Apatite replacement and rare earth mobility, fractionation, and fixation during weathering.* Clay Mineralogy, 37, 113-127

Birkeland, P.W., 1999. *Soils and Geomorphology*, 3rd ed. Oxford Univ. Press, New York, p. 372.

Blake, G.R. & Hartge, K.H., 1986. *Bulk Density. in: Klute, A., (Ed.), Methods of Soil analysis, Part 1. Physical and Mineralogical Methods.* Agronomy Monograph No: 9. SSSA, Madison, WI, 363-375. 393 p.

Bouyoucous, G.J., 1951. A R*ecalibration of the Hydrometer Method for Making Mechanical* Analysis of Soils. Agron, 43, 434-438

Braun, J.-J., Viers, J., Durpré, B., Polve, M., Ndam, J., & Muller, J.P., 1998. *Solid/liquid REE fractionation in the lateritic system of Goyoum, east Cameroon: the implication for the present dynamics of the soil covers of the humid tropical regions.* Geochimica et Cosmochimica Acta, 62(2), 273-299.

Buggle, B., Glaser, B., ller, L.Z., Hambach, U., Markovic' S., Glaser, I. & Gerasimenko, N., 2008. *Geochemical characterization and origin of Southeastern and Eastern European loesses (Serbia, Romania, Ukraine)* Quaternary Science Reviews, 27, 1058-1075

Caspari, T., Baumler, R., Norbu, C., Tshering, K., & Baillie, I., 2006. *Geochemical investigation of soils developed in different lithologies in Bhutan, Eastern Himalayas.* Geoderma, 136(1-2), 436-458.

Chao, T.T. & Sanzolone, R.F., 1992. *Decomposition Techniques.* Journal of Geochemical Exploration, 44, 65-10.

Çelik, M. & Karakaya, N., 1998. *Systematic Mineralogy* 434 p.

Delgado, R., Delgado, G., Párraga, F.J., Gámiz, E., Sánchez-Maranõn, M. & Tenorio, M.A., 1987. *Mapa de suelos escala 1:100.000 de Gűejar Sierra (1027).* Publicaciones del Ministerio de Agricultura, Pesca y Alimentacio´n, Madrid.

Dinç, U., Şenol, S., Kapur, S., Atalay, İ. & Cangir, C., 1999. *Soil of the Turkey.* Çukurova University Adana, 243 p.

DMI, (1994). *Meteorological Bulletin.* Turkish State Meteorological Service

Egli, M., Mirabella, A., Sartori, G. & Fitze, P., 2003. *Weathering Rates as a Function of Climate: Results from a Climosequence of the Val Genova (Trentino, Italian Alps).* Geoderma, 111, 99-121.

Egli, M., Merkli, C., Sartori, G., Mirabella, A. & Plötz,

M., 2007. *Weathering, mineralogical evoluation and soil organic matter along holocene soil toposequence developed on carbonate-rich materials*. Geomorphology, 97, 675-696

Eppes, M.C., Bierma, R., Vinson, D. & Pazzaglia, F. J., 2008**.** *A soil chronosequence study of the Reno Valley, Italy: Insights into the relative role of climate verses anthropogenic forcing on hill slope processes during the mid-Holocene:* Geoderma, 147, 97-107.

Fedo, C.M., Nesbitt, H.W. & Young, G.M., 1995. *Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance*. Geology, 23, 921-924.

Feldman, S.B., Zelazny, L.W. & Baker, J.C., 1991. *High-elevation forest soils of the southern Appalachians: I. Distribution of parent materials and soil–landscape relationships.* Soil Science Society of America Journal, 55, 1629-1637.

Glade, T., 2003. *Landslide occurrence as a response to land use change: a review of evidence from New Zealand.* Catena, 51, 297-314.

Graham, R.C., Herbert, B.E. & Ervin, J.O., 1988. *Mineralogy and incipient pedogenesis of Entisols in anorthosite terrain of the San Gabriel Mountains, California.* Soil Science Society of America Journal, 52, 738-746.

Graham, R.C., Daniels, R.B., Buol, S.W., 1990. *Soil-geomorphic relations on the Blue Ridge Front: I. Regolith types and slope processes.* Soil Sci. Soc. Am. J. 54, 1362– 1367.

Harnois, L., 1988. *The CIW index: A new chemical index of weathering. Sedimentary* Geology, 55, 319-322.

Jackson, M.L., 1979. *Soil Chemical Analysis.* Advanced Course. Department of Soil Science University of Wisconsin, Madison, Vis. 53706, 468-509.

Kabata-Pendias, A., & Pendias, H., 2001. *Trace Elements in Soils and Plants,* 3rd ed. CRC Press, Boca Raton, 315 p.

Land, M., Őhlander, B., Ingri, J., & Thunberg, J., 1999. *Solid speciation and fractionation of rare earth elements in a spodosol profile from northern Sweden as revealed by sequential extraction.* Chemical Geology, 160, 121-138.

McLennan, S.M., Hemming, S., McDaniel, D.K. & Hanson, G.N., 1993. *Geochemical approach to sedimentation, provenance, and tectonics.* Special. Paper. Geology. Society of America, 284, 21-40.

Middleburg, J.J., Van der Weijden, C.H. & Woittiez, J.R.W., 1988. *Chemical processes affecting the mobility of major, minor and trace elements during the weathering of granite rocks*. Chemical Geology, 68, 253–273.

Nesbitt, H.W., Markovics, G. & Price, R.C., 1980. *Chemical processes affecting alkalis and alkaline earths during continental weathering*. Geochimica et Cosmochimica Acta, 44, 1659-1666.

Nesbitt, H.W. & Young, G.M., 1982, *Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. N*ature, 299(5885), 715-717.

Pan, Y. & Stauffer, M.R., 2000. *Cerium anomaly and Th/U fractionation in the 1.85 Ga Flin Flon Paleosol: clues from REE- and U-rich accessory minerals and implications for paleoatmospheric reconstruction.* American Mineralogist, 85, 898-911.

Parker, A., 1970, *an Index of weathering for silicate rocks.* Geological Magazine, 107, 501-504.

Price, P., R., Michael A. & Velbel, M., A., 2003. *Chemical weathering indices applied to weathering profiles developed on heterogeneous felsic metamorphic parent rocks*. Chemical Geology, 202, 397- 416.

Reiche, P., 1943. *Graphic representation of chemical weathering.* Journal of Sedimentary Petrology, 13, 58-68.

Schollenberger, C.J. & Simon, R.H., 1954. *Determination of exchange capacity and exchangeable bases in soil–ammonium acetate method.* Soil Science, 59, 13-24.

Soil Survey Laboratory Methods Manuals 2004. *United States Department of Agriculture Natural Resources Conservation Service,* Soil Survey Investigations Report No. 42, p. 700.

Soil Survey Staff, 1999. *Soil Taxonomy: a Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2nd edition. U*SDA-SCS Agri. Handbook. United State Government Printing Office, Washington, DC. p.869

Taylor, S.R. & McLennan, S.M., 1985. *The Continental Crust: its Composition and Evolution.* Blackwell, London, 311 p.

Van Lagen, B., 1993. *Manual for Chemical Soil Analyses.* Department of Soil Science and Geology, Wageningen University, the Netherlands., p. 100.

White, A.F., 1995. *Chemical weathering rates of silicate minerals in soils.* In: White, A.F., Brantley, S.L. (Eds.), Chemical Weathering Rates of Silicate Minerals. Mineralogical Society of America Special Publication, vol. 31. Mineralogical Society of America, Washington D.C., 407–461.,

Xing, B. & Dudas, M.J., 1993. *Trace and rare earth element content of white clay soils of the three river plain, Heilongjiang Province, P.R. China.* Geoderma 58 (3-4), 181-199.

Wood, D.,A., Tarney, J., Varet, J., Saunders, A.D., Bougault, H., Joron, J.L., Treuil, M. & Cann, J.R., 1979.*Geochemistry of Basalts drilled in the North Atlantic by IPOD Lg 49: Implications for Mantle Heterogeneity.* Earth and Planetary Science Letters, 42, 77-97