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WEATHERING RATES AND SOME PHYSICO-CHEMICAL CHARACTERISTICS OF SOILS DEVELOPED ON A CALCIC TOPOSEQUENCES

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Abstract: Soil formations were highly associated with topographic positions which have influence on morphological, mineralogical and weathering process of the soils. Because, topography or relief affects how water and other material are added to and removed from soils. The aim of this study is to carry out a pedological assessment of the soils classified as Regosol, Cambisol and Vertisol by taking into consideration FAO classification system formed on different topographic position and the same parent rocks (limestone-marl). In addition the second aim of this research is to answer the question about the difference in classification resulting from pedogenic processes or from other factors by determining the degree of weathering soils using geochemical data. For this aim, after macro-morphological identifications were completed for three representative soil pedons, the soil samples were then collected from the horizons to investigate the analytical characteristics such as mineralogical, geochemical and physio-chemical properties. The study will also take into account other features such as the pedogenic evolution of soils using weathering indices such as CIA, CIW, Base/R_2O_3, WIP and PIA. According to results, CIA, CIW, PIA and WIP index values of all soils varied between 66.75-73.87, 73.48 - 81.79, 57.60-68.49, respectively. In addition it was found that the bases/R_2O_3 values of most of the soils were below 1.0. The results clearly showed that topographic condition strongly affects on soil physic-chemical, mineralogical and morphological properties either directly or indirectly in the local region. This case was also explained with chemical weathering indices in this study.

Key Words: Soil Formation, toposequence, weathering index, geochemical evolution

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 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.

Soil toposequences 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. 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.

Stoichiometric 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.

Soil formation in sloping 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 (Grantham 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 & Boul, 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.

The aim of this study is to carry out a pedological assessment of the soils that are classified as Regosol, Cambisol and Vertisol 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 late quaternary soil formation.

2. MATERIALS AND METHODS

2.1. Site Description

This study was carried out in Samsun-Bafra delta plain and near district. The Bafra Plain found in the Kızılırmak Delta and located in the central Black Sea region of Turkey (Fig. 1). The study area is far 30 km from west of the Samsun province (4602-4609 km N- 234-242 km E UTM / WGS 84).

It ranges in relief from 2 m to 150 m and three landscape positions (floodplain, backslope, shoulder), representing changes in geomorphology, topographic gradients and soil characteristics, were selected on left side of Kızılırmak River. The underlying bedrocks within the study area consist of primarily quaternary alluvial and colluvial deposits that belongs to quaternary age spotted on and footslope and marl-lime stone that belongs to mesozoic age located on shoulder and back slope lands.

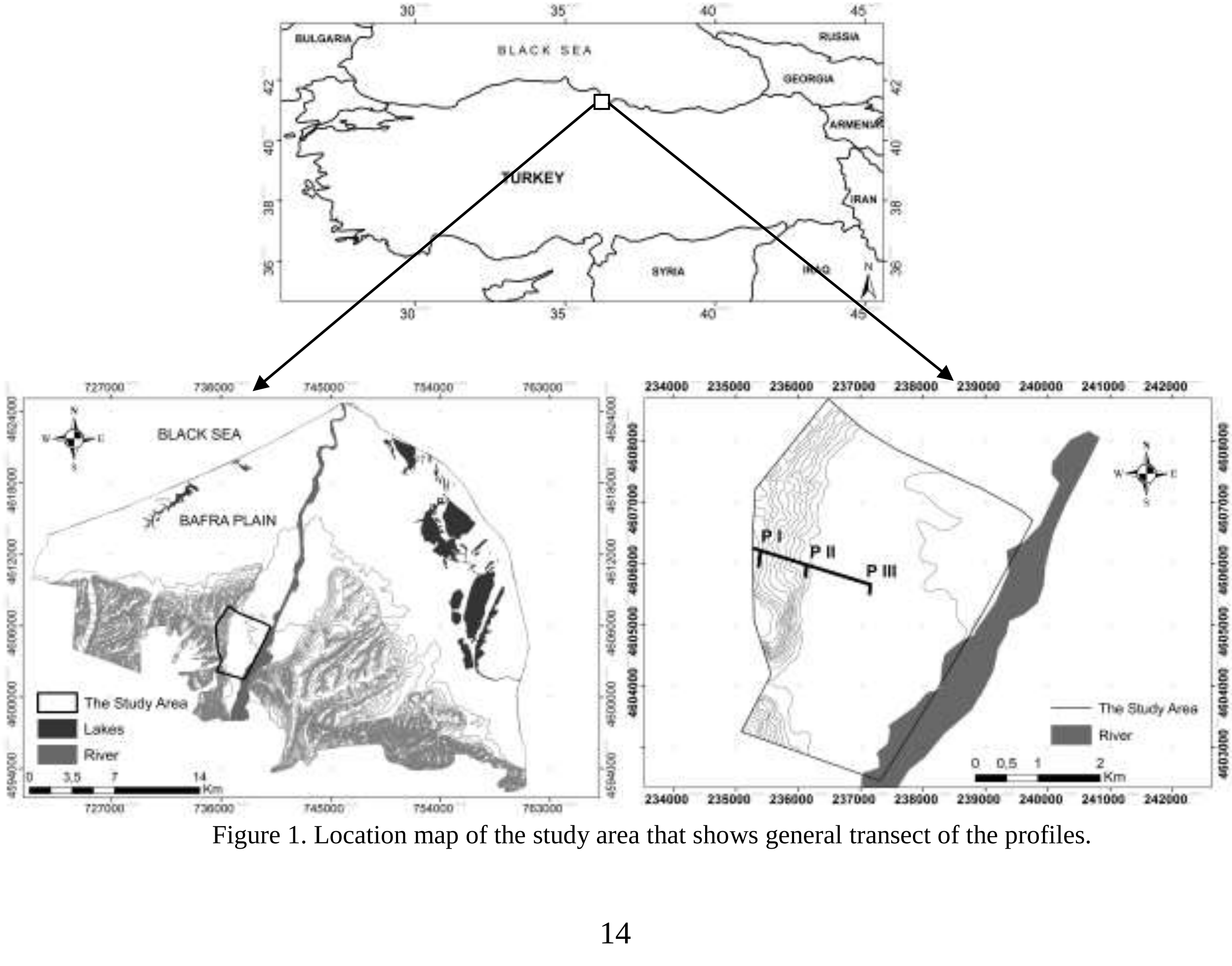

Figure 1. Location map of the study area that shows general transect of the profiles.

The current climate in the region is semi-humid. The summers are warmer than winters (the average temperature in July is 22.2 and in January is 6.9^{o}C). The mean annual temperature, rainfall and evaporation are 13.6ºC, 764.3 mm and 726.7 mm respectively. According to Soil Taxonomy (1999), the study site has mesic soil temperature regime and ustic moisture regime. The study area has two major physiographic units. Particularly river alluvial plain is common and it has slightly sloped (0.0-2.0%) and second unit is hilly and moderately to severe sloped (3-20%). Flat land of the study area has been under intensive agricultural activities. Rice, wheat, maize, pepper, watermelon, cucumber and tomato with sprinkler and furrow irrigations in the summer, and cabbage and leek in the winter have been produced in the study area. The main water resource to this area is Kızılırmak River. The study area has been commonly used for irrigated agriculture. Presently, the irrigation systems used by farmlands are furrow, drip and sprinkler irrigation systems.

2.2. Soil Sampling and Analysis

Based on the hypothesis that topography and parent material and also climate-vegetation cover might be the main controlling factor in soil development, soils have been studied on along transect (crosswise from West to East direction) with representative three profiles (Fig. 2). Morphological properties of these three profiles in the field were identified and sampled by genetic horizons and classified according to Soil Survey Staff (1993 and 1999). 26 disturbed and undisturbed soil samples were taken to investigate for their physical, chemical and mineralogical properties at the laboratory. Soil samples were then air-dried and passed through a 2 mm sieve to prepare for laboratory analysis.

2.3. Physical, chemical and mineralogical analysis

After soil samples were then air-dried and passed through a 2 mm sieve, particle size distribution was determined by the hydrometer method (Bouyoucos, 1951) after removal of organic matter with 30 % H_2O_2, of sulphate by leaching salts with distilled water, of carbonates with 1 M NaOAC at pH 5, and dispersion by agitating the sample in 10 ml of 40% sodium hexametaphosphate (calcon) (Gee & Bauder 1986). Bulk density (Blacke & Hartge 1986) was determined from undisturbed samples. Organic matter and total nitrogen were determined in air-dry samples using the Walkley-Black wet digestion method (Nelson & Sommers, 1982). pH, EC-electrical conductivity (of the saturation) by method of the (Soil Survey Laboratory, 2004). Lime content by Scheibler calsimeter (Soil Survey Staff 1993). Exchangeble cations and cation exchange capacities (CEC) were measured using a 1 N NH_4OAC (pH 7) method (Soil Survey Laboratory, 2004).

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 step^{-1}.

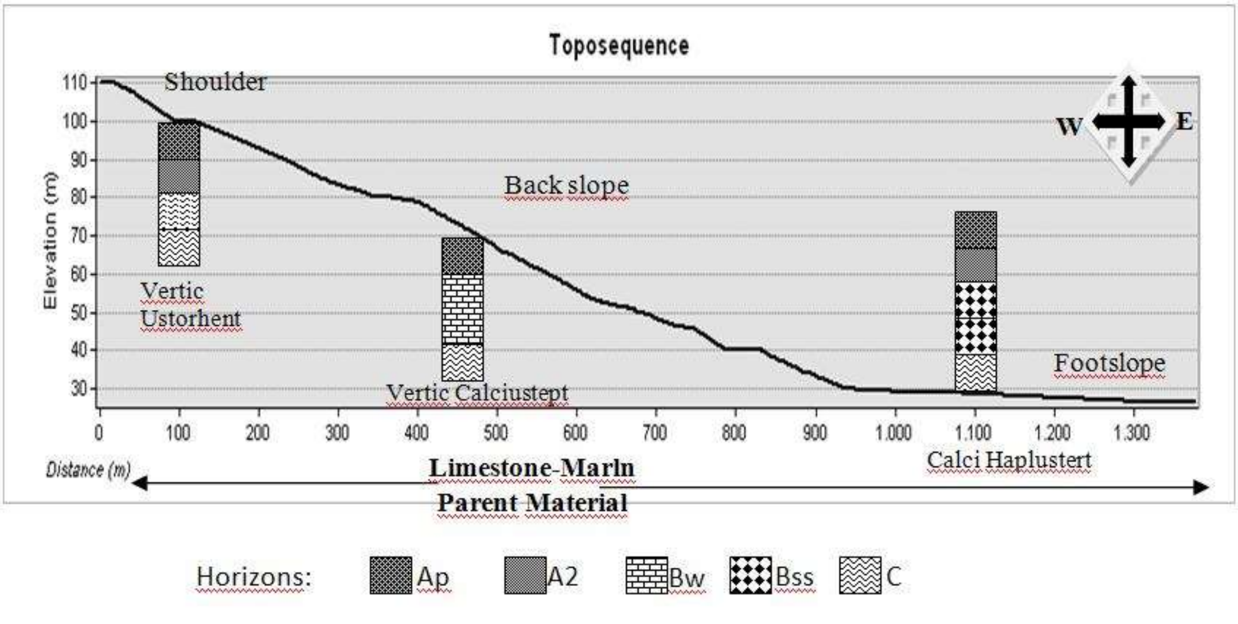

Figure 2. Transect of the three different soil pedons on the same parent material but different topographic positions.

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 (Whittig & Allardice 1986).

Chemical determination of selected major, trace and rare earth elements was performed by Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Samples were taken in to solution by alkaline fusion using a mixture of 0.25 g soil or sediment powder and 0.75 g flux (lithium tetra and metaborate). 0.2 N HNO_3 solutions diluted to1:1000. An aliquot of the sample solution was analyzed for the trace element and the rare earth element (REE), on a combination simultaneous/Sequential (ICP-MS). Detection limits were 0.1-1 ppm for all major and trace elements and 0.1-0.5 ppm for REE. The instrument was calibrated using certified standard reference materials (OREAS24P and G1). To better evaluate the nature of soils and sediments and the effect of weathering and possible recycling on trace and rare earth elements of sediments under semiarid conditions, reference sediment was chosen for comparison in the study, i.e., North American Shale Composite (NASC) from Taylor and McLennan (1985). All procedures were replicated three times for each soil, and the means were reported (Chao & Sanzolone, 1992).

2.4. Calculation of Weathering Indices

Several indexes have been defined to characterize chemical weathering in soils (e.g. Hornois, 1988; Nesbit & Young, 1982). 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, 1950). In the equations, CaO* is associated with the silicate fraction and corrected for inputs from carbonate and apatite. 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. Besides some geochemical ratios and Ce and Eu anomalies were used to quantification of weathering degree of studied profiles.

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 anomalies can be calculated as follow;

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

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. Cerium anomalies can be calculated as follow;

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

3. RESULTS AND DISCUSSIONS

3.1. Morphological Properties and Classification

Field morphology and physical characterization data for representative pedons of the soils are presented in figure 2 and table 1. Soils along transect of left side of Kızılırmak River display variation in terms of participle distribution, colour, and depth in surface horizon. These variables are the obvious effect of eroding forces. Therefore, surface soils were carried and accumulated from shoulder slope to footslope lands leading to progressively redder, deeper and finer texture soils with decreasing elevation. Soil colours of the left side closely reflected the parent materials are 2.5Y (hue) in shoulder surface and reach a maximum redness in footslope soils 10 YR (hue). Pedon I (PI) developed and located on shoulder slope. Slope has been regarded as one of the most important factor that controls the pedogenic process on PI. Slope contributes to greater runoff, as well as to greater translocation of surface materials (organic matter, fine earth etc.) down slope through surface erosion and movement of soil. Soil color is 2.5 YR 5/3 in the Ap horizon while, due to carbonate accumulation in depth color was change to 5

Y 8/3 in subsurface horizons. Secondary $CaCO_3$ nodules and myceliums were also identified in the PI, which apparently proofed the existence of carbonate leaching and accumulation (Table 1). The horizon orders of the PI were defined to be A-C horizons. This means this profile has no diagnostic subsurface horizons and low pedogenetic development. Therefore, this soil can be defined as a young soil and classified as Eutric Regosol (FAO/ISRIC 2006) and Vertic Ustorthent (Soil Taxonomy, 1999). Figure 2 also schematically illustrates the pedological differences across transect. Clay percentages of pedons that were affected by slope gradient have the following distribution with increasing elevation from 37% to 50%. This result to some extent is concurrence with the result of Kreznor et al., (1989), Rezaei & Gilkes (2005) in their study showed dependency of particle size on landscape attributes, including slope gradients. This changing has also effect on structural development of along the transect soils.

Pedon II (PI) developed and located on back slope of the study area. Clay was the dominant texture in the PI. Soil color is 10 YR 6/3 in the Ap horizon, while, due to carbonate accumulation in depth color was change to 2.5 Y 7/3 in subsurface horizons. Secondary $CaCO_3$ nodules and mycelium were also identified in the PI, which apparently proofed the existence of carbonate leaching and accumulation (Table 1). Calcium carbonate nodules, starting in the Bw2 horizon at a depth of 78 cm, were increased in both thickness and diameter in the Ck horizon. Main subsurface diagnostic horizon is cambic horizon developed as a result of structural formation in this profile. Especially, structural development was observed between 19 and 78 cm depth. According to FAO/ISRIC (2006) and soil taxonomy (1999) this profile was classified as Calcaric Cambisol and as Vertic Calciustept.

While owing to loss of organic matter and fine texture, structural developing of shoulder soils on surface horizon is weak, fine, granular (1fgr), back and foot slopes structure have 2fgr and 2mgr respectively in surface horizons. Maximum structural formation was observed Bss horizons of Pedon III. P III formed on the foot slope of the study area developed on kolluvial clay deposit. This profile has also $CaCO_3$ nodules. Occurrence of the cracks 1-5 cm in width on the surface of this soil in arid periods was a result of excessive amount of clay. This soil has intersecting slickensides and shiny pressure faces in sub surface horizon indicating shrink swell properties of the soil. Granular to moderate medium sub angular blocky structure was noticed in surface horizons, while moderate and strong medium prismatic structure in sub soil horizons. The presence of a layer more than 25 cm thick associated with slickensides close enough to intersect in sub horizons, more than 30 percent clay and 1-5 cm wide cracks up to 1 meter qualify for Vertisol and classified Calcic Vertisol and as Calci Haplusert.

Table 1. Morphological properties and classification (FAO/ISRIC-Soil Taxonomy) of pedons

Horizon	Depth (cm)	Color (dry)	Color (moisture)	Structure	Boundary	Special features
PI	Pedon I (*Eutric Regosol / Vertic Ustorthent*)					
Ap	0-20	2.5 Y 5/3	2.5 YR 4/3	1fgr	as	
A2	20-59	2.5 Y 7/3	2.5 Y 5/4	2mgr	cw	
C_1k	59-100	2.5 Y 8/3	2.5 Y 6/4	mas	gw	common carbonate nodules and micelles
C2	100+	2.5 Y 6/4	2.5 Y 5/4	mas	-	
PII	Pedon II (*Calcaric Cambisol / Vertic Calciustept*)					
Ap	0-19	10 YR 6/3	10 YR 5/3	2fgr	as	cracks
Bw1	19-48	2.5 Y 6/3	2.5 Y 5/3	2msbk	cw	structure development
Bw2	48-78	2.5 Y 6/3	2.5 Y 5/3	3csbk	gw	structure development
Ck	78+	2.5 Y 7/3	2.5 Y 7/4	mas	-	common carbonate noduls
PIII	Pedon III (*Calcic Vertisol / Calci Haplusert*)					
Ap	0-19	10 YR 4/3	10 YR 4/2	2mgr	as	cracks
A2	19-44	10 YR 5/3	10 YR5/4	3mgr/2fsbk	cw	slickenside
Bss1	44-69	10 YR 6/2	10 YR 6/2	3mpr	ci	slickenside
Bkss2	69-111	10 YR 6/2	10 YR 4/3	3cpr	gi	common carbonate noduls
C	111+	2.5Y 6/2	2.5Y 5/3	mas	-	

Abbreviations: Boundary: a = abrupt; c = clear; g = gradual; d = diffuse; s = smooth; w = wavy; i = irregular
Structure: 1 = weak; 2 = moderate; 3= strong; sg = single grain; mas = massive; vf = very fine; f = fine; m =medium; c = coarse; gr = granular; pr = prismatic; abk = angular blocky; sbk = subangular blocky.

3.2. Physical, Chemical and Mineralogical Properties

The major physical and chemical properties of the soils and major and minor element concentrations of the studied profiles are presented in table 2 and table 3. Soil physical and chemical properties that have been taken into consideration in this study showed variability as a result of dynamic interactions among natural environmental factors such as climate, parent material, land cover-land use and topography (Dengiz, 2010). The pH of the soils was moderately alkaline and there are no significant differences in the values of pH 8.1-8.4. In addition, all pedons have slightly soluble salt content. Clay is dominant texture for all pedons. Calcic Vertisol has the highest clay content while, Eutric Regosol has the highest sand content. Soil CEC varied between 33.1 to 55.9 cmolc kg^{-1}. The soil with the highest CEC was Calci Haplusert with high clay content, while the lowest value was determined in Eutric Regosol soil. Calcium carbonate content of the profiles was found to be high. 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 SiO_2/Al_2O_3 rates. All of the profiles studied were formed on limestone-marl parent material, which led to higher $CaCO_3$ content in the pedons. In addition, the calcium carbonate content was even much higher in the horizons with carbonate accumulation (i.e. calcic horizons) (Table 2). The low amount of $CaCO_3$ in surface horizon of Eutric Regosol can be explained by leaching of $CaCO_3$ in the pedon. Dominant exchangeable cations are Ca+Mg ions for all pedons and the base saturation values were found to be 100%. For all soils, the organic matter is highest in the surface horizon and decreases sharply to its lowest level in the subsoil. In the study area, the reasons of the low level organic matter are attributable to rapid decomposition and mineralization of organic matter. Soil organic matter ranged from 1.7 to 2.3% in upper horizons.

According to X-ray diffractograms (Fig. 3) 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 1.42–1.60 nm, 1.0 nm, and 0.70–0.74 nm. The reflection at 0.72 nm disappeared at 550°C. Glycolation expanded part of the 1.42–1.60 nm peak, with a shoulder at about 1.7–1.8 nm, and the same peak closed to 1.29–1.20 nm after K saturation at 20°C, but at 550°C, an illite-defined diffraction band between 1.0 and 1.1 nm was observed, indicating the presence of smectite, illite, and kaolinite. The most abundant clay mineral is smectite, followed by kaolinite and illite.

3.3. Weathering Indices and Anomalies

Chemical weathering indices are commonly used for characterizing weathering profiles by calculating from molecular proportions typically are based on the assumption that aluminum is immobile (e.g., Vogt, 1927; Ruxton 1968; Nesbitt & Young, 1982; Harnois, 1988; Fedo et al., 1995), an assumption that is not always warranted (Gardner et al., 1978; Gardner 1980, 1992). In addition, the molecular proportion of each oxide is easily calculated from the percent of the oxide based on weight. Generally, on homogeneous parent rocks, weathering indices change systematically with depth. However, the weathering of heterogeneous metamorphic rocks confounds the relationship between weathering index and depth. In this paper, six weathering indices previously defined chemical weathering indices were used and evaluated for pedons developed on limestone-marl parent rocks and different topographic positions. 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.

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 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 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, Özaytekin et al., 2012). This ratio ranged from 70 to 75 for shales.

In the studied pedons, the CIA rate varied between 66.75 and 73.87. The highest CIA value was in the C1k horizon of Eutric Regosol whereas, it was determined that the lowest value was in the Ap horizon of Calcic Vertisol. The CIA values increased with depth in all pedons generally.

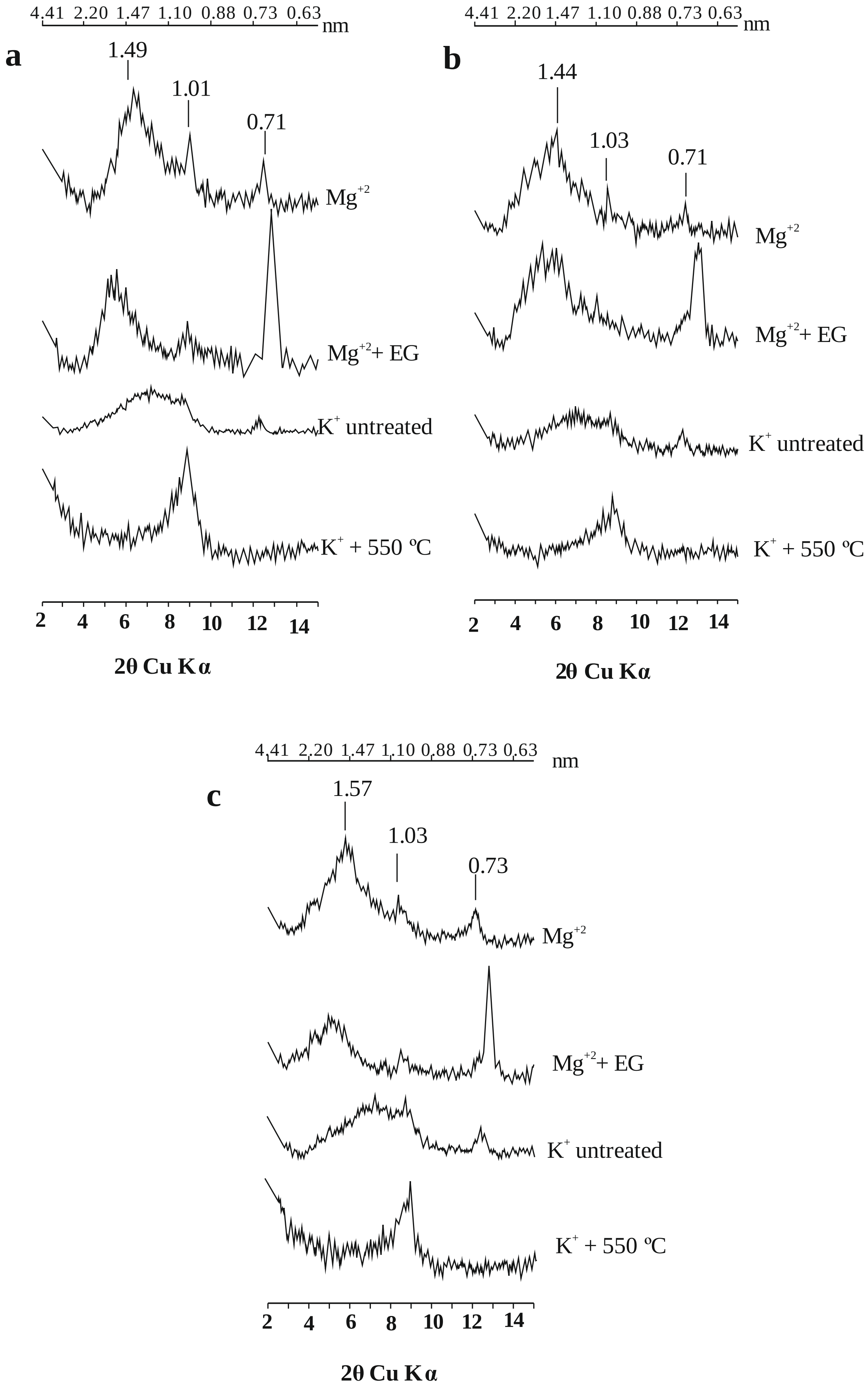

Figure 3. X-ray diffractograms of selected samples: (a)PI-Ap; (b) PII-Ap; (c) PIII-Ap; (Clay minerals); *d*-values in nm.

Table 2. Some physical and chemical properties of studied soils

Horizon	Depth (cm)	$pH_{(H2O)}$ (1/2,5)	EC ($\mu S.cm^{-1}$)	$CaCO_3$ (%)	O.M (%)	Exchangeable Cations ($cmolc \cdot kg^{-1}$)			CEC ($cmolc \cdot kg^{-1}$)	B.D ($gr.cm^{-3}$)	P.S.D (%)			
						Na	K	Ca+Mg			C	Si	S	Class
PI	Pedon I (*Eutric Regosol / Vertic Ustorthent*)													
Ap	0-20	8.1	0.3	2.4	1.7	0.2	0.4	52.7	48.2	1.29	37	46	17	C
A2	20-59	8.3	0.3	27.0	0.5	0.2	0.2	42.2	38.6	1.52	42	33	25	C
C1k	59-100	8.4	0.2	42.9	-	0.2	0.2	30.0	33.1	1.58	36	35	29	CL
C2	100+	8.4	0.3	16.3	-	0.3	0.2	47.4	47.2	1.45	50	28	22	C
PII	Pedon II (*Calcaric Cambisol* / *Vertic Calciustept)*													
Ap	0-19	8.0	0.4	1.6	2.0	0.4	0.5	35.2	44.1	1.31	42	36	22	C
Bw1	19-48	8.2	0.4	3.3	0.5	0.3	0.5	44.5	45.8	1.26	57	26	17	C
Bw2	48-78	8.2	0.5	3.4	0.3	0.3	0.4	45.8	46.9	1.24	60	24	16	C
Ck	78+	8.3	0.5	4.9	0.1	0.4	0.6	44.4	44.1	1.24	55	29	16	C
PIII	Pedon III (*Calcic Vertisol / Calci Haplusert*)													
Ap	0-19	8.2	0.3	6.3	2.3	0.6	0.5	53.1	52.0	1.39	50	33	17	C
A2	19-44	8.2	0.3	7.4	1.5	0.7	0.3	50.1	50.7	1.40	49	36	15	C
Bss1	44-69	8.2	0.4	11.4	1,6	1.0	0.5	54.0	55.9	1.29	61	30	9	C
Bkss2	69-111	8.4	0.4	18.7	0.6	1.4	0.4	49.4	43.6	1.30	56	38	6	C
C	111+	8.3	0.4	8.5	0.7	2.1	0.7	50.7	54.0	-	72	21	7	C

O.M: Organic matter, C.E.C: Cation Excahange Capacity, B.D: Bulk Density, P.S.D: Particle Size Distribution, C: Clay, Si: Silt, S: Sand, CL: Clay Loam

Table 4. Weathering rates of studied soils.

Horizon	CIA	CIW	Base/R_2O_3	WIP	P	PIA
Pedon I (*Eutric Regosol / Vertic Ustorthent*)						
Ap	69.75	76.59	0.495	24.91	85.41	60.82
A_2	73.10	80.63	0.468	23.71	84.93	63.77
C_1k	73.87	81.79	0.450	23.38	84.38	64.19
C_2	73.16	81.31	0.470	23.90	84.58	63.14
Pedon II (*Calcaric Cambisol / Vertic Calciustept*)						
Ap	70.41	75.23	0.471	22.93	85.32	64.01
Bw1	71.67	76.43	0.472	17.55	84.57	65.44
Bw2	72.49	76.75	0.473	13.18	84.94	66.93
Ck	73.74	77.84	0.428	19.15	83.92	68.49
Pedon III (*Calcic Vertisol / Calci Haplusert*)						
Ap	66.75	73.48	0.730	30.99	84.37	57.60
A_2	68.08	74.99	0.728	30.26	83.83	58.86
Bss_1	72.43	80.38	0.853	31.42	80.71	62.54
$Bkss_2$	70.70	78.52	1.038	33.69	80.29	60.74
C	72.38	80.92	0.861	36.35	78.97	61.82

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+Zr)/Sr	Ce/Ce*	Eu/Eu*
I	Ap	1.02	4.51	0.37	0.44	6.90	6.26	3.09	3.16	0.95	0.73
	A_2	0.78	4.24	0.39	0.43	8.76	7.90	3.67	3.11	0.94	0.78
	C_1k	0.67	3.74	0.34	0.38	8.37	8.24	3.83	3.09	0.91	0.75
	C_2	0.69	4.31	0.40	0.34	8.87	8.72	3.91	3.03	0.87	0.73
II	Ap	0.83	3.51	0.36	0.89	8.14	8.00	3.43	2.57	0.98	0.79
	Bw1	0.85	4.37	0.38	0.90	7.97	6.42	3.11	1.62	0.92	0.73
	Bw2	1.03	3.85	0.35	0.99	7.09	7.32	3.17	1.06	0.93	0.75
	Ck	0.79	3.34	0.36	0.87	7.74	7.43	3.16	1.86	1.00	0.79
III	Ap	0.86	4.25	0.35	0.50	7.53	7.49	3.24	1.89	0.94	0.80
	A_2	0.83	4.49	0.36	0.45	7.37	7.95	3.31	1.97	0.90	0.82
	Bss_1	0.84	4.85	0.37	0.34	7.38	6.31	3.45	1.76	0.90	0.84
	$Bkss_2$	0.96	4.33	0.38	0.33	7.06	6.95	3.09	1.21	0.92	0.82
	C	0.88	4.36	0.36	0.29	7.03	7.17	3.22	2.13	0.89	0.80

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

Pedon	Horizon	Major Elements							Minor Elements								LOI	Total
		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Ba	Co	Cs	Nb	Rb	Sr		
I	Ap	63.76	13.56	6.16	1.29	1.52	1.26	1.60	0.81	0.15	373	23.1	5.0	12.2	83.4	147.4	9.6	99.85
	A_2	63.69	14.79	5.29	1.39	2.27	1.08	1.74	0.82	0.08	337	13.9	5.9	11.7	83.7	150.4	8.6	99.85
	C_1k	62.90	15.07	5.78	1.40	2.47	1.02	1.82	0.81	0.06	335	18.2	6.7	13.2	86.2	155.9	8.5	99.86
	C_2	62.23	14.89	5.31	1.41	2.89	1.04	1.88	0.79	0.07	319	10.9	6.4	10.9	91.1	168.1	9.3	99.87
II	Ap	62.43	12.89	6.44	1.25	3.10	1.29	1.08	0.99	0.09	357	29.3	3.7	15.0	56.1	121.8	10.1	99.85
	Bw1	46.47	10.24	4.98	1.08	16.49	0.96	0.82	0.78	0.06	332	20.2	3.1	11.2	43.8	151.4	17.8	99.86
	Bw2	36.50	7.93	3.60	0.86	25.46	0.73	0.56	0.61	0.04	251	12.6	2.6	9.6	29.7	157.0	23.5	99.90
	Ck	53.02	1.48	5.70	1.16	11.15	1.08	0.82	0.91	0.03	315	16.3	3.6	13.9	46.7	140.6	13.4	99.87
III	Ap	57.70	1.13	6.19	2.64	5.18	1.44	1.66	0.86	0.25	389	25.1	4.2	13.5	72.9	215.3	10.5	99.82
	A_2	55.97	13.22	6.35	2.81	5.71	1.34	1.65	0.85	0.15	393	24.2	4.7	12.9	75.4	214.2	11.6	99.82
	Bss_1	47.72	13.75	7.26	4.43	8.19	1.02	1.73	0.79	0.13	388	27.9	5.6	11.8	77.8	246.4	14.6	99.79
	$Bkss_2$	43.07	12.63	6.88	5.26	11.77	1.05	1.64	0.75	0.14	320	28.1	5.6	10.9	68.8	318.4	16.4	99.78
	C	49.12	15.77	8.37	5.15	5.13	1.13	2.12	0.89	0.15	399	34.0	6.5	13.5	93.7	245.8	11.7	99.76

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

Pedon	Horizon	Minor Elements			Rare earth elements (REE)													
		Th	U	Zr	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
I	Ap	9.8	2.6	176.9	26.9	55.3	6.30	26.4	4.99		4.71	0.74	4.26	0.87	2.58	0.39	2.78	0.39
	A_2	10.8	2.2	172.5	25.4	49.5	5.46	22.7	3.97		3.33	0.54	2.92	0.62	2.04	0.30	2.08	0.29
	C_1k	10.9	1.9	156.8	25.1	47.7	5.39	21.8	3.76	0.86	3.33	0.54	2.77	0.62	1.94	0.31	1.97	0.30
	C_2	10.6	1.9	147.6	27.5	49.4	5.88	23.2	4.03	0.89	3.50	0.58	3.20	0.73	1.93	0.33	2.04	0.31
II	Ap	9.7	2.1	238.4	35.0	72.7	7.78	30.9	5.85	1.46	5.56	0.87	5.07	1.02	2.90	0.46	2.83	0.43
	Bw1	7.2	1.6	188.7	23.9	47.3	5.49	21.1	4.41	0.97	3.84	0.60	3.61	0.74	2.18	0.30	2.41	0.30
	Bw2	5.6	1.5	140.7	16.3	32.6	3.74	16.0	2.95	0.69	2.73	0.41	2.41	0.51	1.34	0.23	1.44	0.23
	Ck	9.2	1.9	195.2	24.0	53.0	5.83	22.4	4.36	1.03	3.70	0.64	3.40	0.70	1.97	0.33	2.09	0.31
III	Ap	8.9	2.0	173.9	27.1	54.8	6.22	23.9	4.79	1.21	4.52	0.75	4.06	0.84	2.50	0.39	2.34	0.36
	A_2	8.3	1.8	162.3	25.8	50.1	5.96	24.4	4.47	1.17	4.38	0.71	3.92	0.83	2.32	0.39	2.10	0.35
	Bss_1	8.7	1.9	126.6	23.6	46.8	5.64	21.0	3.92	1.08	4.00	0.66	3.66	0.76	2.08	0.33	2.42	0.32
	$Bkss_2$	8.8	2.2	109.8	21.9	44.6	5.29	19.9	4.06	1.03	3.70	0.63	3.37	0.74	2.04	0.32	2.04	0.31
	C	10.0	2.3	129.9	26.7	51.7	6.24	23.6	4.75	1.21	4.59	0.75	4.17	0.85	2.45	0.36	2.41	0.38

In other words, parent materials of all pedons have the highest CIA values in layers. Nesbitt and Young (1982) classified the CIA values as very slightly weathered (50-60), slightly weathered (60-70), moderately weathered (70-80), highly weathered (80-90), and extremely weathered (90-100). When it was evaluated values by taking into consideration of CIA classification, surface horizons of pedons except for Calcaric Cambisol are slightly weathered. On the other hand, it was determined that all sub surface horizons were in the same class. In addition there is an obvious trend progressively higher alteration values in Eutric Regosol as compared to other soils. This case can be explained that fine surface materials transported so, parent material exposed to soil formation factors.

Chemical weathering indices are commonly used for characterizing weathering profiles by incorporating bulk major element oxide chemistry into a single metric for each sample. Harnois (1988) suggested weathering index (CIW) which modified CIA. CIW eliminated K_2O from CIA. Owing to assumed immobility of Al and higher mobility of Na, K, and Ca, CIW increases with the increase of weathering degree. In the case of K-feldspar rich rock, CIW might have a tendency to show larger values even for unweathered rock because CIW does not account for the behaviour of Al which is associated with K-feldspar. The CIW values ranged between 73.48 and 81.79 and tended to increase with depth in the studied all pedons. The value increased with weathering. If the classification for CIA is performed for CIW as well, it is evident that all the pedons developed on different topographic positions are different classes in terms of CIW values. This result indicates that although all pedons have the same parent material, the soils studied have some morphological differentiations and they are affected under different weathering conditions. The bases/R_2O_3 values of all soils were below 1.0 in all profiles except for Bkss horizon of Calcic Vertisol, ranging from 0.428 to 1.038.

Parker's Weathering Index is based on the proportions of alkali and alkaline earth metals (sodium, potassium, magnesium and calcium) present. These elements are the most mobile of the major elements, and there is no need to assume that sesquioxide concentration remains approximately constant during weathering. The WIP also takes into account the individual mobilities of sodium, potassium, magnesium and calcium, based on their bond strengths with oxygen (Parker, 1970). In addition, Price & Velbel (2003) evaluated some weathering indices in their studies and they reported that the (WIP) was the most appropriate for application to weathering profiles on heterogeneous (and homogeneous) parent rock. Because the WIP includes only the highly mobile alkali and alkaline earth elements in its formulation, it yields values that differ greatly from those of the parent rock. The WIP index values in the studied soils formed on limestone-marl parent rocks were distributed between 13.18 and 36.35. The value of WIP decreased with weathering. The lowest WIP values ranged between 13.18 and 22.93 were determined in Calcaric Cambisol whereas, Calcic Vertisol has the highest WIP values (30.26-36.35). This case can be explained with two reasons. Firstly, this means that weathering process is higher in Calcaric Cambisol as compared to Calcic Vertisol. Second is topographic position. Because, topography or relief so strongly affects pedogenetic processes of soils due to effect of eroding forces. Surface soils were carried and accumulated from uplands to low lands leading to progressively deeper and finer texture soils with decreasing elevation. Calcic Vertisol is located on footslope. Therefore, Calcic Vertisol include high amount of clay content due to weathering and accumulation leading to high amount of basic cations retention in soils.

The P index varied between 78.97 and 85.41. It tended to decrease with depth in all pedons. In addition, Fedo et al., (1995) proposed the Plagioclase Index of Alteration as an alternative to the CIW. Because plagioclase is abundant in silicate rocks and dissolves relatively rapidly, the PIA may be used when plagioclase weathering needs to be monitored (Fedo et al., 1995). The PIA value showed a similar variation in pedons and ranged between 57.60 and 68.49. No regular change trend in Eutric Regosol and Calcic Vertisol was observed, it tended to increase with depth in Calcaric Cambisol.

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. Negative Eu and Ce anomalies were found in the soils studied, their values ranged between 0.87-1.00 and 0.73-0.84, respectively.

Another way to study the degree of chemical weathering of the investigated soil pedons is to calculate the relative change of REE (Rare Earth Element) 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 and McLennan 1985). Some geochemical ratios were used to quantification of weathering degree of studied pedons. The trace elements and REEs of the studied soils normalized to chondrite (Wood et al., 1979). Normalized REE patterns can reflect the degree of weathering of materials, and this also applies to a lesser extent to the light rare earth element (LREE) fraction. Among the geochemical rates calculated to determine weathering, the Th/U value ranged between 0.67 and 1.03. The lowest value was seen in Eutric Regosol in horizon C2. Ba/Nb was distributed between 3.34 and 4.85. No regular change trend in pedons with depth. Sr made substation in spite of Ca in $CaCO_3$. (Rb+Zr)/Sr, the variation was between 1.06 and 3.16. The variation interval in the pedons in terms of limestone content was large. Ti and Zr are often considered to be almost immobile. To better estimate elemental gain and loss from 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 pedons studied, some rates were examined to quantify weathering by using Ti and Zr. In the rates obtained using Ti and Zr, showed homogenous values. Ti/Nb ranged between 0.34 and 0.40, and Zr/Rb ranged between 0.29 and 0.99. The La/Lu rate is an important indicator used in weathering and provenance studies in soils. This value ranged between 6.90 and 8.87. The change curve of the La/Yb and La/Sm values between soils, an important indicator of LREE, heavy rare earth element (HREE) enrichment, and, in turn, clay movement in soils had quite a similar distribution trend. These rates ranged between 6.26-8.72 and 3.09-3.91, respectively.

4. CONCLUSION

In the study area, the main negative impact of soil forming factor on profile development in hillslope positions (shoulder and back slope) is soil erosion. Soil erosion and mass movement or landslides are important geomorphic processes in mountainous terrain. While soil development proceeds on all parts of the regolith-covered landscape, it can be interrupted at any stage by mass movement event. This interruption is relatively common on high slope degree, so Regosol often predominant there. Therefore, these soils can be defined as young soils. This event was observed in this present study. In addition to that, soils in lower slope position (back slope-foot slope) classified as Calcic Vertisol and Calcaric Cambisol showed differences in terms of more development sub surface profile due to no interruption events. Main subsurface diagnostic horizons of these soils are cambic and calcic horizons. The results clearly showed that topographic condition strongly affects on soil physic-chemical, mineralogical and morphological properties either directly or indirectly in the local region. This case also explained with chemical weathering indices such as CIA, CIW, Base/R_2O_3 (Al_2O_3 + Fe_2O_3 *ses*-quioxide or R_2O_3) and PIA in this study. They are commonly used for characterizing weathering profiles by incorporating bulk major element oxide chemistry into a single metric for each sample. In this paper, we evaluated previously defined chemical weathering indices for their suitability in characterizing weathering pedons developed on limestone-marl parent rocks and different topographic positions. The fact that the physical, chemical and mineralogical characteristics in the pedons are similar and had limited variation and that the weathering indexes and anomalies determined using geochemical characteristics showed a very limited variation along pedons indicates that the pedons show similar weathering levels despite their different ages.

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