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CHEMICAL WEATHERING RATES AND GEOCHEMICAL-MINERALOGICAL CHARACTERISTICS OF SOILS DEVELOPED ON HETEROGENEOUS PARENT MATERIAL AND TOPOSEQUENCE

Tülay TUNÇAY[1] & Orhan DENGİZ[2]
[1]*Soil Fertilizer and Water Resources Center Research Instıtue, Ankara, Turkey, tulaytuncay@gmail.com*
[2] *Ondokuz Mayis University Agricultural Faculty Department of Soil Science and Plant Nutrition-Samsun, Turkey odengiz@omu.edu.tr*

Abstract: Mineral weathering is an environmentally significant process and stage in the formation of soils. In addition, soil formations are highly associated with topographic positions that have influence on the morphological, mineralogical, and weathering processes of the soils. That is because topography or relief affects how water and other materials are added to and removed from soils. The aim of this study was to carry out a pedological evaluation of the soils classified as vertisols, inceptisols, and entisols by taking into consideration a soil taxonomy classification system based on different topographic positions and the same parent rocks. The second aim of this research was to answer questions about the differences in classification resulting from pedogenic processes or from other factors by quantifying the maturity stages and the degree of soil weathering using geochemical, mineralogical, and other analytical data. To accomplish this, after macro-morphological identifications were completed for three representative soil pedons, soil samples were collected from the horizons to investigate analytical characteristics such as mineralogical, geochemical, and physicochemical properties. The study took into account other features, including the pedogenic evolution of soils using weathering indices such as CIA, CIW, Base/R_2O_3, WIP, and PIA. The results showed clearly that topographic conditions strongly affect soil physicochemical, mineralogical, and morphological properties, either directly or indirectly in the local region. That conclusion was also supported by chemical weathering indices in this study.

Keywords: Soil formation, toposequence, weathering indices, major and minor elements

1. INTRODUCTION

Soils develop within weathered, unconsolidated (parent) materials at the earth's surface under the influence of biota and climate. Soil cannot form within solid rock, but it can form within the weathered byproducts of that rock (Mandel & Bettis, 2001; Schaetzl & Anderson, 2005; Jenny, 1941). A significant stage in the formation of soil from rock involves weathering of rock into smaller and/or chemically altered parts (Yatsu, 1988). Weathering rates depend upon the composition of the rock, temperature range, and rainfall amount. It is well known that weathering is the physical and chemical alteration of rocks and minerals at or near the earth's surface, produced by biological, chemical, or physical agents or their combination (Pope et al., 2002). Soil is the biogeochemically altered material that lies at the interface between the lithosphere and atmosphere. It is widely recognized that soils play a key role in controlling the storage, transformation, and flux of nutrients and carbon through the lithosphere and biosphere (Davidson et al., 2006; Heimann & Reichstein, 2008).

Physical weathering is physical disintegration of rock into smaller fragments, each with the same properties as the original, and occurs mainly by temperature and pressure changes. Chemical weathering is a process by which the internal structure of a mineral is altered by the addition or removal of elements. It is dependent upon the available surface area for reaction, temperature, and the presence of chemically active fluids. All three processes may act independently, but will, more often than not, occur simultaneously. Different circumstances will result in one weathering process being more important than another. The processes may also act in concert. The chemical weathering rates on continents are regulated by many factors, including the source rock type, climate regime, tectonic and topographic settings, vegetation, soil development, and human activities (Oliva et al., 2003; Gaillardet et al., 1997; Meybeck, 1987). Chemical weathering a dynamic geochemical process, where minerals in a soil, has been reported in several geochemical studies of weathering (Neall, 1977; Duzgoren-Aydin et al., 2002; Price & Velbel, 2003; Özaytekin & Karakaplan, 2012).

Chemical weathering indices, direct chemical indicators such as Weathering Index of Parker (WIP), Plagioclase Index of Alteration (PIA), Chemical Index of Weathering (CIW), Chemical Index of Alteration (CIA), and Vogt's Residual Index (V), have been used worldwide as proxies to evaluate the chemical weathering intensity in specific weathering profiles (Shao et al., 2012). Zhang et al., (2007) indicated that macroelement indicators include primarily the major elements related to soil formation, Si, Al, and Fe, and easily mobilized elements such as Ca, Mg, K, and Na.

Among these weathering indices, CIA, proposed by Nesbitt & Young (1982), and WIP, developed by Hamdan & Burnham (1996), are the most commonly applied indices. Parker (1970) proposed WIP for silicate rocks on the basis of element mobility, which is related to the bond strength of each element (Na, K, Mg, Ca) with oxygen. These mobile elements will be leached during weathering, and concentrations of these elements will diminish correspondingly. As the WIP involves only the highly mobile alkali and alkaline earth elements in its formulation, its values have differed greatly from those of the parent rock (Harnois, 1988; Price & Velbel, 2003). Vogt (1927) proposed a weathering index (V) to assess the maturation degree of residual sediments. Owing to Al immobility (or lower mobility) and higher mobility of Na, Mg and Ca, V increases with an increasing degree of weathering (Roaldset, 1972). Nesbitt & Young (1982) suggested a weathering index (CIA) to estimate paleoclimate from early Proterozoic sediments of the Huronian Supergroup on the north shore of Lake Huron. CIA is interpreted as an indicator of the degree of conversion of feldspars to clay such as kaolinite. Harnois (1988) proposed a weathering index (CIW) that modified CIA. CIW eliminated K_2O from the equation of CIA. Fedo et al., (1995) proposed an alternative index to CIW. Because silicate rocks contain a high amount of plagioclase, which dissolves more rapidly than other minerals, PIA is likely better for weathering evaluation when plagioclase weathering needs to be monitored. Owing to the assumption of Al immobility and higher mobility of other elements (Na and Ca), PIW will increase as the weathering proceeds. Leaching of K also makes PIW increase independently, regardless of Ca and Na leaching.

By considering weathering indices and geochemical and mineralogical data, the present study has carried out a pedological evaluation aimed at identifying individual mineralogical and geochemical characteristics of vertisols, inceptisols, and entisols with different parent materials and located on different topographies. The aim was to understand the relationship between particular soils and the landscapes and ecosystems in which they function. Geochemical, mineralogical, and other analytical characteristics are presented here 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 the southern part of the Samsun-Bafra Plain, located in the Kızılırmak Delta in the central Black Sea Region of Turkey (Fig. 1). The study area is located approximately 200 km west of the Samsun provincial center (4598500-4597500 N, 749250-750 000 E, UTM/WGS 84 m).

The study area ranges from 20 m to 130 m in relief and includes four landscape morphologies (floodplain, backslope, shoulder, and summit) representing changes in geomorphology, topographic gradient, parent material, and soil characteristics. The underlying bedrock consists primarily of Quaternary alluvial and colluvial deposits on the footslope and low backslope and Mesozoic basalt and marl-limestone on the summit, shoulder, and high backslope. The current climate in the region is semi-humid. Summers are warmer than winters (average temperatures: July, 22.2^{o}C; January, 6.9^{o}C). The mean annual temperature, rainfall, and evaporation are 13.6ºC, 764.3 mm, and 726.7 mm, respectively. Soil temperature and water moisture regimes at the study site were classified according to the Soil Survey Staff (Soil Taxonomy, 1999) as mesic and ustic, respectively. Physiographically, the area is comprised of four main units. The majority of the site consists of a slightly sloped (0.0-2.0%) alluvial plain, and other units are hilly and moderately to severely sloped (3-20%). Pasture and fruit orchards of apple, peach, pear, and cherry cover most of the area.

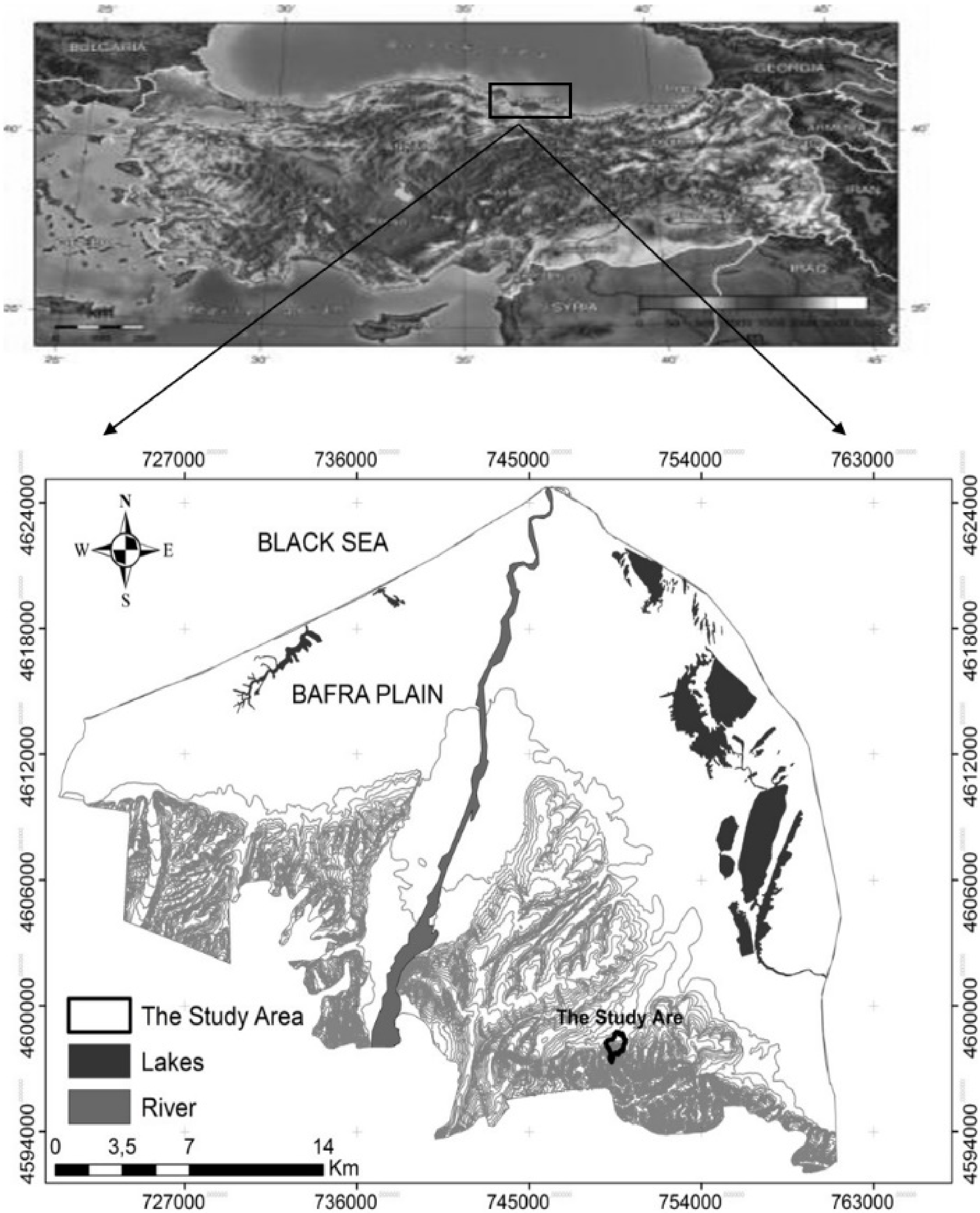

Figure1. Location map of the study area

2.2 Soil sampling and analysis

Soils were studied along a west-to-east transect with six representative profiles (Fig. 2) to test the hypothesis that topography, parent material, and climate-vegetation cover might be the main controlling factors in soil development. Morphological properties of these six profiles were identified and sampled by genetic horizons and classified according to Soil Survey Staff (1993 and 1999). A total of 26 disturbed and undisturbed soil samples were taken to investigate their physical, chemical, and mineralogical properties in the laboratory. Soil samples were then air dried and passed through a 2-mm sieve to prepare them for laboratory analysis.

2.3 Physical, chemical, and mineralogical analysis

After the soil samples were air dried and passed through a 2-mm sieve, particle size distribution was determined by the hydrometer method (Bouyoucos, 1951).

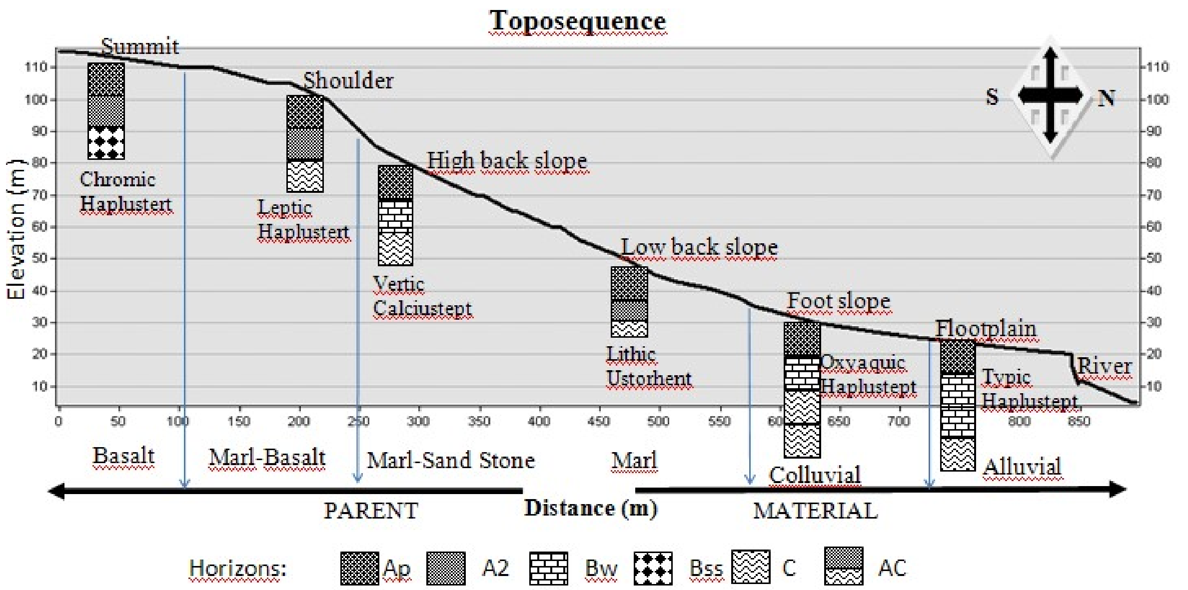

Figure 2. Transect of the six different soil pedons on different parent material and topographic positions

Organic matter was removed with 30% H_2O_2, sulphate by leaching salts with distilled water, and carbonates with 1 M NaOAC at pH 5 with dispersion by agitating the sample in 10 ml of 40% sodium hexametaphosphate (Calgon) (Gee & Bauder, 1986). Bulk density (Blacke & Hartge, 1986) was determined from undisturbed samples. Organic matter and total nitrogen were determined in air-dried samples using the Walkley-Black wet digestion method (Nelson & Sommer, 1982). Methods of the Soil Survey Laboratory (2004) were used to determine values of pH and EC (electrical conductivity) of the saturation. Lime content was measured by a Scheibler calsimeter (Soil Survey Staff, 1993). Exchangeble cations and cation exchange capacities (CEC) were measured using a 1 N NH4OAC (pH 7) method (Soil Survey Laboratory, 2004).

The clay fraction (<2 μm) was obtained from the soil after the destruction of organic matter with dilute and Na-acetate-buffered H_2O_2 (pH 5), and 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 two seconds per step. The following treatments were performed: Mg saturation, ethylene glycol solvation (EG), and K saturation, followed by heating for two hours 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 into solution by alkaline fusion using a mixture of 0.25 g soil or sediment powder and 0.75 g flux (lithium tetra- and metaborate) in 0.2 N HNO3 solutions diluted to1:1000. An aliquot of the sample solution was analyzed for trace elements and rare earth elements (REE) on a combination simultaneous/sequential ICP-MS. Detection limits were 0.1-1.0 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 of trace and rare earth elements in sediments under semiarid conditions, reference sediment was used for comparison in the study. North American Shale Composite (NASC) from Taylor & McLennan (1985) was chosen for that purpose. All procedures were replicated three times for each soil, and the mean values were reported (Chao & Sanzolone, 1992).

2.4 Calculation of weathering indices

Several indices have been defined to characterize chemical weathering in soils (e.g. Hornois, 1988; Nesbit & Young, 1982). The general principle of all these indices is similar and based on the ratio of the base cations (Ca, Mg, K, and Na) to Al and Si. Weathering indices used for the quantification of chemical weathering intensity in this udy included 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 of carbonate and apatite. CaO* is based on the assumption that the molar CaO/Na_2O ratio of silicates is not higher than one. When the molar CaO content (corrected for apatite) was less than the molar Na_2O content, the 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, 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 AND DISCUSSION

3.1 Morphological properties and classification

Descriptions of the study site and six representative soil pedons are presented in table 1 and figure 2. Pedons I and II are located on flat land and gentle slopes, Pedons III and VI on moderate slopes, and Pedons IV and V on steep slopes.

Soils in the study area display variation in terms of particle distribution, color, and surface horizon depth.

These differences represent the obvious effect of erosion, whereby surface soils have been carried from the shoulder slope to the foot slope, their accumulation leading to progressively darker, deeper, and finer-textured soils with decreases in elevation. Soil color is closely reflective of the parent material, marlstone, with a hue of 2.5Y on the shoulder surface, darkening progressively to reach a maximum value of 10YR on the footslope. The color of the surface soil in Pedon VI, located on the summit, is also dark, reflecting its parent material, basalt. The accumulation of calcium carbonate in Pedon IV and the redoximorphic features in Pedon II are indicative of pedological developments reflected in the variations in color, particle size distribution, and surface horizon depth. Highly mottled areas observed in the footslope are indicative of poor drainage locally and reflect the influence of topography on microclimate (Idoga et al., 2006). The subsurface horizon (below 88 cm) of the footslope is predominately a hue of grey (5/5B), suggesting soils comprised of fine-textured colluvial and alluvial material. For all pedons, soil profiles included a strongly or moderately developed A horizon with a granular, angular, blocky structure; a strongly or moderately developed B horizon with an angular blocky structure; and a C horizon with a massive or graded structure (Table 2).

Both Soil Taxonomy (1999) and FAO/ISRIC (2006) classification systems were used in this study. Accordingly, Pedon I, located on a floodplain and formed on alluvial parent material, was classified as Typic Haplustept and Vertic Cambisol, respectively. The main diagnostic horizon in Pedon I is the subsurface cambic horizon, resulting from structural development, observed especially at depths between 30 and 98 cm.

Pedon II was classified as Oxyaquic Haplustept and Oxyaquic Cambisol. In addition to the subsurface cambic diagnostic horizon found in Pedon I, Pedon II also has redoximorphic features such as grayish mottles.

Pedon III was classified as Lithic Ustorhent and Lithic Leptosol. Slope was regarded as one of the most important factors controlling the pedogenic process in this pedon, which is located on a high backslope. Slope contributes to greater runoff, as well as to greater translocation of surface materials downslope through surface erosion and movement of soil.

Soil horizons in Pedon III were identified as A, AC, and Cr, with no diagnostic subsurface horizons and low pedogenetic development, indicating it to be a young soil. On the other hand, due to the the presence of secondary $CaCO_3$ nodules, mycelia, and carbonate leaching and accumulation at greater depths, Pedon IV was classified as Vertic Calciustept (Soil Taxonomy, 1999) and Calcaric Cambisol (FAO/ISRIC, 2006).

Pedon V was classified as Lithic Haplustert and as Haplic Vertisol. Soils in this pedon, located on the shoulder and summit, were formed from a basalt parent material and contain a large amount of clay. That is indicated by surface cracks ranging from 1-5 cm in width, as well as intersecting slickensides and shiny pressure faces in the subsurface horizon that also reflect a shrinking and swelling of the soil. The subhorizons in this pedon include a layer more than 25 cm thick associated with slickensides and lithic contact at a depth of 50 cm.

Pedon VI was also classified as Chromic Haplustert and Chromic Vertisol. Similar to Pedon V, this pedon formed on basalt parent material located on the shoulder and summit and showed cracking in arid periods due to high clay content. Intersecting slickensides and shiny pressure faces were found in the subsurface horizon.

3.2 Physical and chemical characteristics

The major physical and chemical properties of the soils in each pedon in the study area are presented in table 3.

Table 1. Selected site characteristics of pedons

Pedon	Coordinates (WGS 84-UTMm)		Parent Material	Elevation (m)	Slope Position	Slope (%)	Land cover / Land Use
	East	North					
I	749718	4598608	Alluvial deposit	20	Flat	0-2	Fruit (apple) cultivation
II	749666	4598375	Kolluvial deposit	22	Foot slope	4-6	Fruit (peach) cultivation
III	749529	4598263	Marl	63	Low back slope	6-12	Fruit (peach) cultivation
IV	749284	4598109	Sand stone-Lime stone, Marl	83	High back slope	12-20	Pasture
V	749484	4597741	Basalt, Sand stone	120	Shoulder	20-30	Fruit (apple) cultivation
VI	749634	4597893	Basalt	130	Summit	6-12	Fruit (apple) cultivation-Pasture

Table 2. Morphological properties and classification (FAO/ISRIC-Soil Taxonomy) of pedons

Horizon	Depth (cm)	Color (dry)	Color (moisture)	Structure	Boundary	Special features
PI	Pedon I *(Typic Haplustept/ Vertic Cambisol*)					
Ap	0-30	10YR 4/4	2.5Y 3/3	2fmgr	as	-
Bw1	30-85	10YR 4/4	2.5Y 3/3	2mgr	cw	structure development
Bw2	85-98	10YR 5/4	2.5 Y 4/4	2msbk	gw	structure development
C	98+	10YR 4/2	2.5Y 4/3	mas	-	-
PII	Pedon II (*Oxyaquic Haplustept / Oxyaquic Cambisol)*					
Ap	0-23	2.5 Y 4/4	2.5 Y 4/3	2fgr	as	cracks
Bw	23-64	2.5 Y 5/3	2.5 Y 4/3	2msbk	cw	structure development
C1g	64-88	2.5 YR 5/6	2.5 YR 4/6	mas	gw	few mottles
C2g	88+	Gley 6/5B	Gley 5/5B	mas	-	common mottles
PIII	Pedon III (*Lithic Ustorhent / Lithic Leptosol*)					
Ap	0-10	2.5 Y 7/4	2.5 Y 6/6	2mgr	as	-
AC	10-30	2.5 Y 7/4	2.5 Y 6/6	3mgr/2fsbk	cw	-
PIV	Pedon IV (*Vertic Calciustept / Calcaric Cambisol)*					
Ap	0-22	2.5 Y 6/4	2.5 Y 5/4	2mgr	as	-
Bw	22-43	2.5 Y 5/6	2.5 Y 5/4	2msbk	gw	structure development
Ck	43-95	2.5 Y 8/3	2.5 Y 7/6	mas	-	common carbonate nodules and mycelia
P V	Pedon V (*Lithic Haplustert / Haplic Vertisol)*					
A	0-19	10 YR4/3	10 YR 4/4	3mgr	aw	cracks
Bss	19-50	10 YR 5/3	10 YR 5/4	2mabk	cw	-
2C	50+	2.5 Y 7/2	2.5 Y 6/3	mas and sg	-	-
P VI	Pedon VI (*Chromic Haplustert / ChromicVertisol)*					
A1	0-18	10 YR 5/3	10 YR 5/3	2mgr	cw	cracks
A2	18-48	10 YR 5/4	10 YR 5/3	3cgr and 2mabk	gw	-
Bss	48+	10 YR 6/3	10 YR 6/4	3cabk	-	slickenside

Abreviations: 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

Properties in the different pedons varied as a result of a dynamic interaction among environmental factors including climate, parent material, land cover/land use, and topography (Dengiz, 2010; Kibar et al., 2012). Solum depth ranged from 20 to 102 cm, depending upon topographic position. All pedons had a moderately alkaline soil pH (pH 7.55-8.26) and a slightly soluble salt content, with no significant differences among pedons.

Table 3. Some physical and chemical properties of soils

Horizon	Depth (cm)	$pH_{(H2O)}$ (1/2,5)	EC ($dS.cm^{-1}$)	$CaCO_3$ (%)	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
P I	Pedon I (*Typic Haplustept / Vertic Cambisol*)														
Ap	0-30	7.85	0.26	3.2	1.9	7.8	6.9	19.0	2.6	39.3	1.43	38.8	25.2	35.9	CL
Bw1	30-85	7.78	0.26	1.1	1.8	8.3	3.9	18.3	2.9	33.8	1.50	38.2	29.3	32.4	CL
Bw2	85-98	7.55	0.24	1.3	1.1	8.2	2.8	22.3	4.5	28.5	1.45	38.5	27.6	33.7	CL
C	98+	8.20	0.23	2.2	0.8	9.0	2.7	22.1	2.7	39.7	-	41.0	26.8	32.0	C
P II	Pedon II (*Oxyaquic Haplustept / Oxyaquic Cambisol)*														
Ap	0-23	8.01	0.45	2.4	1.9	7.5	4.5	27.8	0.9	39.1	1.50	42.9	23.8	33.2	C
Bw	23-64	7.97	0.48	3.5	1.8	3.8	3.8	24.8	4.9	26.4	1.40	47.5	23.3	29.1	C
C1g	64-88	7.64	0.83	0.4	1.1	6.8	4.9	25.1	2.7	36.4	1.36	41.4	28.1	30.3	C
C2g	88+	7.56	0.73	0.6	0.5	5.7	4.7	23.6	4.8	36.2	-	49.2	28.5	22.2	CL
P III	Pedon III (*Lithic Ustorhent / Lithic Leptosol*)														
Ap	0-10	8.24	0.26	6.9	0.7	5.6	5.1	19.8	5.4	33.8	1.60	44.8	24.1	31.0	C
AC	10-30	8.09	0.29	22.3	0.5	4.2	4.0	21.1	5,0	31.5	1.48	48.5	29.3	22.1	C
P IV	Pedon IV (*Vertic Calciustept / Calcaric Cambisol)*														
Ap	0-22	7.92	0.24	3.4	1.1	4.2	1.8	24.5	2.2	31.1	1.61	38.5	20.8	40.6	CL
Bw	22-43	8.01	0.19	11.8	0.7	8.6	1.7	24.0	3.1	34.6	1.23	43.3	32.1	24.5	C
Ck	43-95	7.96	0.54	17.2	0.4	6.7	1.4	22.7	3.3	37.7	-	51.9	30.3	17.6	C
P V	Pedon V (*Lithic Haplustert / Haplic Vertisol)*														
A	0-19	7.71	0.34	0.9	2.7	7.6	6.0	14.6	5.85	42.1	1.32	41.4	17.3	41.1	C
Bss	19-50	7.75	0.29	0.8	1.5	6.7	5.8	16.75	1.1	30.3	1.46	49.9	15.2	34.8	C
2C	50+	8.04	0.17	15.9	0.3	7.3	3.2	13.65	3.7	20.3	-	15.6	9.35	75.0	SL
P VI	Pedon VI (*Chromic Haplustert / ChromicVertisol)*														
A1	0-18	8.12	0.33	7.1	1.5	14.4	3.6	22.7	5.5	41.5	1.49	54.7	19.8	25.3	C
A2	18-48	8.13	0.39	2.0	0.7	12.0	2.8	21.8	4.5	44.9	1.41	56.6	17.7	25.6	C
Bss	48+	8.26	0.57	2.3	0.2	22.8	1.9	19.5	8.6	44.8	1.34	58.4	19.5	22.0	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

The dominant soil texture for all pedons was clay or clay loam, with the highest clay content found in the Chromic Vertisol and the highest sand content in the Vertic Cambisol. Soil CEC varied from 26.4 to 44.9 cmolc kg^{-1}, with the highest CEC in the Chromic Vertisol, in which smectite was the predominant clay type, indicating the presence of stratified aluminosilicates with a high load intensity. The lowest Cation Exchange Capacity (CEC) value was found in soil classified as Oxyaquic Cambisol Ca+Mg was the dominant exchangeable cation for all pedons, with a base saturation value of 100%. For all pedons, the organic matter content was highest in the surface horizon (0.2-2.7%) and lowest in the subsurface horizons, with a sharp decrease between the two. The low levels of organic matter in the subsoil can be attributed to the rapid decomposition and mineralization of organic matter. Soil bulk density values ranged from 1.32 to 1.61 g cm^{-3}, with values generally higher in surface horizons (especially Ap horizons) than subsurface horizons as a result of compaction from relatively intensive field traffic associated with agricultural activities. $CaCO_3$ content was close to the detection limit in Pedon I and Pedon II, located on alluvial and colluvial parent material, especially in surface horizons, and ranged from to 2.4 to 3.2%. In addition, Lithic Ustorhent and Calcaric Cambisol were formed on marl parent material, which led to higher $CaCO_3$ content in the pedons. The calcium carbonate content was even much higher in the horizons with carbonate accumulation (calcic horizons) (Table 2). Chromic Vertisol developed on basaltic parent material has calcium carbonate content from 2.0-7.1%. Lime in basaltic primary material is known to have four sources. These are: 1) basaltic lavas taking some part of underlying limy material into its body while flowing; 2) minerals in basalt, which include Ca, forming $CaCO_3$ in the appropriate environment; 3) crystallization of hydrothermal waters, which are rich in lime, in vesicles and fissures after the flow of basaltic lavas; and 4) recalcification with wind-borne limy materials (Özaytekin & Karakaplan, 2012). Similar to our findings, Aksoy (1991) found a lime content of 2-26% in soils on the Kayacik plains in Gaziantep, although the primary material in the area of their study was basalt.

3.3 Weathering indices, some genetic ratios and clay mineralogy

Chemical weathering indices are commonly used for characterizing weathering profiles by calculating from molecular proportions and 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). That assumption 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 on the basis of 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 (Dengiz et al., 2013). In this paper, six previously defined chemical weathering indices were used and evaluated for six pedons. The pedons are developed on Quaternary alluvial and colluvial deposits on the footslope and low backslope positions and Mesozoic basalt and marl-limestone on the summit, shoulder, and high backslope positions. Major and minor element concentrations of the studied pedons, some weathering rates obtained from the geochemical features of the soils in the study, and some genetic rates are shown in Tables 4, 5, and 6, respectively. The CIA represents the degree of 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 soluble cations (e.g. Ca, Na, and K) from the minerals during 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, whereas unweathered upper crustal rocks have a CIA value of 50 (Fedo et al., 1995; Özaytekin & Karakaplan, 2012). The ratio ranges from 70 to 75 for shales. In the studied pedons, the CIA rate varied from 18.16 to 65.71. The highest and lowest CIA values were in the A1 horizon and C horizon of Haplic Vertisol, respectively. The CIA values decreased with depth in all pedons. In other words, parent materials of all pedons have the lowest CIA values of all layers, except for Pedon III, which is classifed as Lithic Leptosol. Nesbitt & 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). Upon evaluation per the CIA classification, surface horizons of all pedons except for Lithic Leptosol are slightly weathered. On the other hand, it was determined that all subsurface horizons are in the same class. In addition, there is an obvious trend toward progressively higher alteration values in Haplic Vertisol and Vertic Cambisol as compared to

Lithic Leptosol. That can be explained by the transportation of fine surface materials exposing the parent material 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 a weathering index (CIW) that modified CIA by eliminating K_2O from CIA. Because of the 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 behavior of the Al associated with K-feldspar. The CIW values ranged between 18.80 and 77.72 and tended to decrease with depth in all pedons studied except for Lithic Leptosol. The value of CIW 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 in different classes in terms of CIW values. This result indicates that, since all pedons have diferent parent material and are located on different topographic positions, the soils studied have some morphological differentiations and are affected under different weathering conditions. Lithic Leptosol has the lowest weathering value, whereas Haplic Vertisol has the highest CIW due to parent material effect. The bases/R_2O_3 values of Vertic Cambisol were below 1.0 in all profile, whereas values of Chromic Vertisol were mostly greater than 1.0, ranging from 0.92 to 1.30.

Parker's Weathering Index (WIP) is based on the proportions of alkali and alkaline earth metals (sodium, potassium, magnesium, and calcium) present. Those 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 on the basis of 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 values in the studied soils formed on alluvial deposit, colluvial deposit, marl, and basalt parent rocks were distributed 16.61-19.46, 15.52-26.83, 38.10-47.52, and 13.17-70.08, respectively. The value of WIP decreased with weathering. The lowest WIP values ranged between 13.17 and 15.12 and were determined in Haplic Vertisol's genetic horizons, whereas the A horizon of Lithic Leptosol has the highest WIP value. There are two explanations for that. First, it means that the weathering process is more intense in Haplic Vertisol than in Lithic Leptosol. Second is topographic position, because topography or relief strongly affects pedogenetic processes of soils due to the effect of erosional agents. Surface soils were carried and accumulated from uplands to lowlands, leading to progressively deeper and finer-textured soils with decreasing elevation. That result can be seen in Haplic Vertisol. Although Haplic Vertisol is located on a shoulder position, it has high clay accumulation, and its parent material is shown as 2C (sandstone), which means that this parent material does not belong to upper soil horizons. Therefore, this pedon has high clay content due to weathering and accumulation leading to a high retention rate of basic cations in the soils. The P index varied between 77.90 and 83.89. It tended to decrease with depth in all pedons. In addition, Fedo et al. (1995) proposed the Plagioclase Index of Alteration (PIA) 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 14.76 and 52.61. No regular change trend in Oxyaquic Cambisol and Calcaric Cambisol was observed; the value tended to decrease with depth in Chromic Vertisol.

Another way to study the degree of chemical weathering of the investigated soil pedons is to calculate the relative change in 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 & McLennan, 1985). Some geochemical ratios were used to quantify the degree of weathering of studied pedons. The trace elements and REEs of the studied soils were 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 fraction. Among the geochemical rates calculated to determine weathering, the Th/U value ranged between 0.01 and 1.42 in all pedons. The lowest value was seen in Vertic Cambisol in genetic horizon Bw2. The Ba/Nb ratio was distributed between 5.6 and 144.2.

Table 4. Some major and minor element concentrations of the studied pedons

Pedon/ Horizon		Major Elements (%)									Minor Elements (ppm)							
		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Ba	Zn	Cu	Pb	Ni	Nb	Rb	Sr
I	Ap	58.53	13.31	7.93	1.68	2.49	0.54	2.43	0.86	0.13	563	69.1	39.8	21.5	61.8	9.9	76.3	168
	Bw1	58.42	13.67	6.93	1.64	1.91	0.71	2.59	0.86	0.14	620.1	73.6	35.3	22.0	56.9	15.2	79.9	193.4
	Bw2	57.49	13.27	7.18	1.67	4.19	0.36	2.36	0.88	0.10	562.4	68.1	34.4	21.8	69.6	3.9	82.5	177.1
	C	56.65	13.34	7.09	1.45	3.17	0.43	2.23	0.90	0.06	597.2	67.4	34.5	22.1	65.2	17.5	76.5	173.6
II	Ap	55.48	13.02	7.67	1.63	2.50	0.16	2.21	0.92	0.10	561.2	71.0	38.8	21.4	66.6	11.5	81.1	140.6
	Bw	52.12	13.76	7.52	2.17	7.45	0.09	2.05	0.89	0.09	456.3	66.2	34.0	18.0	85.8	17.1	78.7	161.5
	C1g	58.80	13.05	7.47	1.63	1.98	0.57	2.64	0.90	0.21	639.5	75.9	32.5	20.4	56.4	12.2	79.5	209.3
	C2g	59.89	13.60	7.85	1.64	2.57	0.89	2.76	0.92	0.25	758.3	84.0	38.5	26.1	60.8	12.8	83.5	222.9
III	Ap	44.47	13.06	7.02	2.15	18.59	0.08	2.13	0.80	0.10	327.0	72.4	37.8	16.1	68.2	14.9	89.4	244.0
	AC	48.72	13.41	7.21	2.20	14.77	0.08	2.39	0.78	0.11	369.4	84.2	44.8	17.5	64.5	11.6	98.9	210.6
IV	Ap	50.92	13.29	7.43	1.69	10.25	0.09	2.03	0.81	0.10	414	76.1	41.0	20.8	126.7	74.3	73.0	163.5
	Bw	47.73	12.94	7.95	1.76	13.15	0.09	2.48	0.80	0.11	382.7	86.8	47.8	16.7	71.1	11.2	104.4	220.5
	Ck	45.85	13.79	7.92	1.72	21.31	0.09	2.45	0.87	0.12	402.8	92.9	46.9	21.5	84.3	9.2	98.4	208.7
V	A1	53.48	15.94	9.46	1.74	2.24	0.34	3.45	0.93	0.14	983.7	97.6	34.4	28.3	32.9	13.7	67.5	281.1
	A2	53.53	14.44	7.03	1.48	2.40	0.22	2.29	0.79	0.24	569.6	77.2	34.8	20.6	60.0	12.7	85.1	147.7
	2C	31.55	10.57	6.18	1.67	5.01	0.08	1.82	0.44	0.11	947	57.9	26.8	17.3	24.1	22.0	35.0	284.8
VI	A1	47.98	15.81	8.21	1.60	6.43	0.09	2.00	0.95	0.08	1124	64.1	25.9	23.9	49.6	13.5	57.9	194.2
	A2	46.52	15.06	7.82	1.56	8.74	0.09	1.89	0.92	0.07	1033	60	28.2	29.5	54.9	12.0	54.3	200.8
	Bss	42.39	17.21	7.65	1.85	8.71	0.09	1.83	0.86	0.08	1275	63.2	27	25.4	55.2	16.0	55.3	269.6

Table 4. Continued

Pedon	Horizon	Rare earth elements (REE-ppm)													
		La	Ce	Ga	Ge	As	Se	Br	Eu	In	Sn	Sb	Te	Ta	Hf
I	Ap	26.7	58.5	14.2	0.8	8.5	0.4	7.7	1.2	0.8	1.8	1.2	1.3	6	5.1
	Bw1	34.2	73.6	15.1	1.7	9.1	0.6	9.1	1.3	0.8	1.8	1.0	0.8	5.9	5.0
	Bw2	26.7	71.9	15.5	0.9	10.1	0.4	8.5	1.1	0.9	3.2	1.0	0.8	5.9	6.5
	C	31.3	60.4	13.9	1.6	9.1	0.4	7.6	0.2	0.8	3.3	1.2	0.6	5.9	5.0
II	Ap	31.7	80.0	15.3	1.9	10.2	0.4	7.7	1.3	0.8	2.2	1.0	0.9	6.1	5.6
	Bw	25.7	61.3	14.9	1.1	11.2	0.4	7.5	1.2	0.9	2.6	1.1	0.8	6.0	4.9
	C1g	24.4	62.3	13.5	1.3	12.3	0.4	9.1	0.5	0.8	2.5	1.0	1.3	5.8	7.5
	C2g	39.8	80.3	16.0	1.0	8.7	0.4	6.8	0.3	0.8	2.9	0.9	1.3	6.1	5.2
III	Ap	25.8	60.2	16.4	1.3	10.6	0.6	2.0	0.8	0.9	2.3	1.5	1.3	6.7	5.6
	AC	31.4	52.4	15.7	1.2	10.3	1.0	1.8	0.2	0.9	1.0	1.0	1.3	6.5	5.6
IV	Ap	108.5	143.0	15.0	0.8	9.1	1.1	6.7	1.2	0.4	1.1	3.9	66.1	6.5	7.4
	Bw	24.0	56.0	17.7	1.5	7.9	0.5	3.2	0.9	0.9	2.0	1.0	1.3	7.0	5.7
	Ck	104.5	115.7	18.2	0.6	9.9	1.6	6.5	0.2	59.1	59.1	53.6	57.9	6.3	10.5
V	A1	34.4	88.1	18.7	0.7	6.6	0.4	7.0	1.4	0.9	1.1	1.0	1.4	6.0	5.1
	A2	31.9	58.0	14.0	1.6	8.5	0.4	9.2	1.2	0.8	2.8	0.9	1.4	5.7	6.1
	2C	160	168	13.4	0.8	0.8	1.2	8.6	0.4	124.7	115.7	105.4	117.8	5.7	10.8
VI	A1	44.6	85.4	15.4	1.7	8.2	0.4	9.6	1.3	0.5	1.8	0.9	1.3	5.3	4.6
	A2	105.4	188.4	12.9	1.4	7.9	1.1	6.6	1.2	81.5	77.8	65.9	78.2	6.1	11.9
	Bss	151.3	178.0	14.4	1.1	7.6	1.4	6.2	1.0	99.6	104	84.6	102.4	5.5	9.8

There was no regular change trend in pedons with depth, and the highest weathering was determined to be in the Ap horizon of Calcaric Cambisol. There is a degree of substitution of Sr for Ca in $CaCO_3$, and the variation in (Rb+Zr)/Sr was between 0.94 and 2.86. The variation of limestone content in the pedons was large. Ti and Zr are often considered to be almost immobile. Immobile index elements such as Ti or Zr are often used to better estimate elemental gain and loss from weathering and to calculate the mass balance relative mobility of other elements and soil discontinuities.

Table 5. Weathering rate indices of studied soils

Horizon	Depth (cm)	CIA	CIW	WIP	PIA	P	Baz/R_2O_3	V
Pedon I, Typic Haplustept/ Vertic Cambisol								
Ap	0-30	62.63	71.52	16.61	50.20	83.89	0.64	1.66
Bw1	30-85	65.20	75.28	16.46	51.81	83.61	0.59	1.90
Bw2	85-98	55.33	61.95	19.46	44.65	83.55	0.78	1.28
C	98+	60.25	67.65	16.69	49.32	83.31	0.65	1.56
Pedon II, Oxyaquic Haplustept / Oxyaquic Cambisol								
Ap	0-23	64.48	73.17	13.35	52.61	82.95	0.58	1.73
Bw	23-64	46.35	50.11	26.83	38.87	81.60	1.07	0.83
C1g	64-88	64.19	74.70	15.52	50.13	83.85	0.59	1.85
C2g	88+	60.37	69.62	19.64	47.09	83.54	0.65	1.64
Pedon III, Lithic Ustorhent / Lithic Leptosol								
Ap	0-10	29.76	31.41	47.52	24.51	81.42	1.93	0.45
AC	10-30	35.70	38.35	38.10	28.79	81.13	1.55	0.59
Pedon IV, Vertic Calciustept / Calcaric Cambisol								
Ap	0-22	56.88	62.81	17.31	47.43	81.76	0.74	1.27
Bw	22-43	32.60	34.97	40.45	25.82	80.80	1.62	0.55
Ck	43-95	39.01	42.18	33.07	31.48	80.73	1.28	0.71
Pedon V, Lithic Haplustert / Haplic Vertisol								
A1	0-19	65.71	77.72	15.12	50.26	79.49	0.54	2.18
A2	19-50	63.48	72.69	13.17	50.80	83.35	0.60	1.77
2C	50+	18.16	18.80	70.08	14.76	77.90	3.41	0.25
Pedon VI, Chromic Haplustert / ChromicVertisol								
A1	0-18	47.78	51.99	22.58	39.68	80.66	0.92	0.94
A2	18-48	39.99	42.92	28.32	33.18	81.04	1.19	0.70
Bss	48+	38.38	41.19	29.05	31.57	80.51	1.30	0.64

Table 6. Some genetic ratios using rare earth elements (REE) of studied soils

Pedon	Horizon	Th/U	Ba/Nb	Zr/Rb	(Rb+Zr)/Sr
I	Ap	1.12	56.9	3.21	1.91
	Bw1	0.82	40.8	2.76	1.56
	Bw2	0.49	144.2	2.68	1.71
	C	0.68	34.1	3.31	1.90
II	Ap	1.27	48.8	2.74	2.16
	Bw	0.99	26.7	2.49	1.70
	C1g	0.72	52.4	3.10	1.56
	C2g	1.08	59.2	2.55	1.33
III	Ap	1.06	21.9	2.08	1.13
	AC	1.16	31.8	1.74	1.29
IV	Ap	0.83	5.6	5.41	2.86
	Bw	0.96	34.2	1.50	1.18
	Ck	0.03	43.8	2.98	1.88
V	A1	1.23	71.8	2.91	0.94
	A2	1.17	44.9	2.46	2.00
	2C	0.01	43.0	11.14	1.49
VI	A1	1.37	83.3	3.41	1.31
	A2	1.13	86.1	6.70	2.08
	Bss	1.42	79.7	7.72	1.79

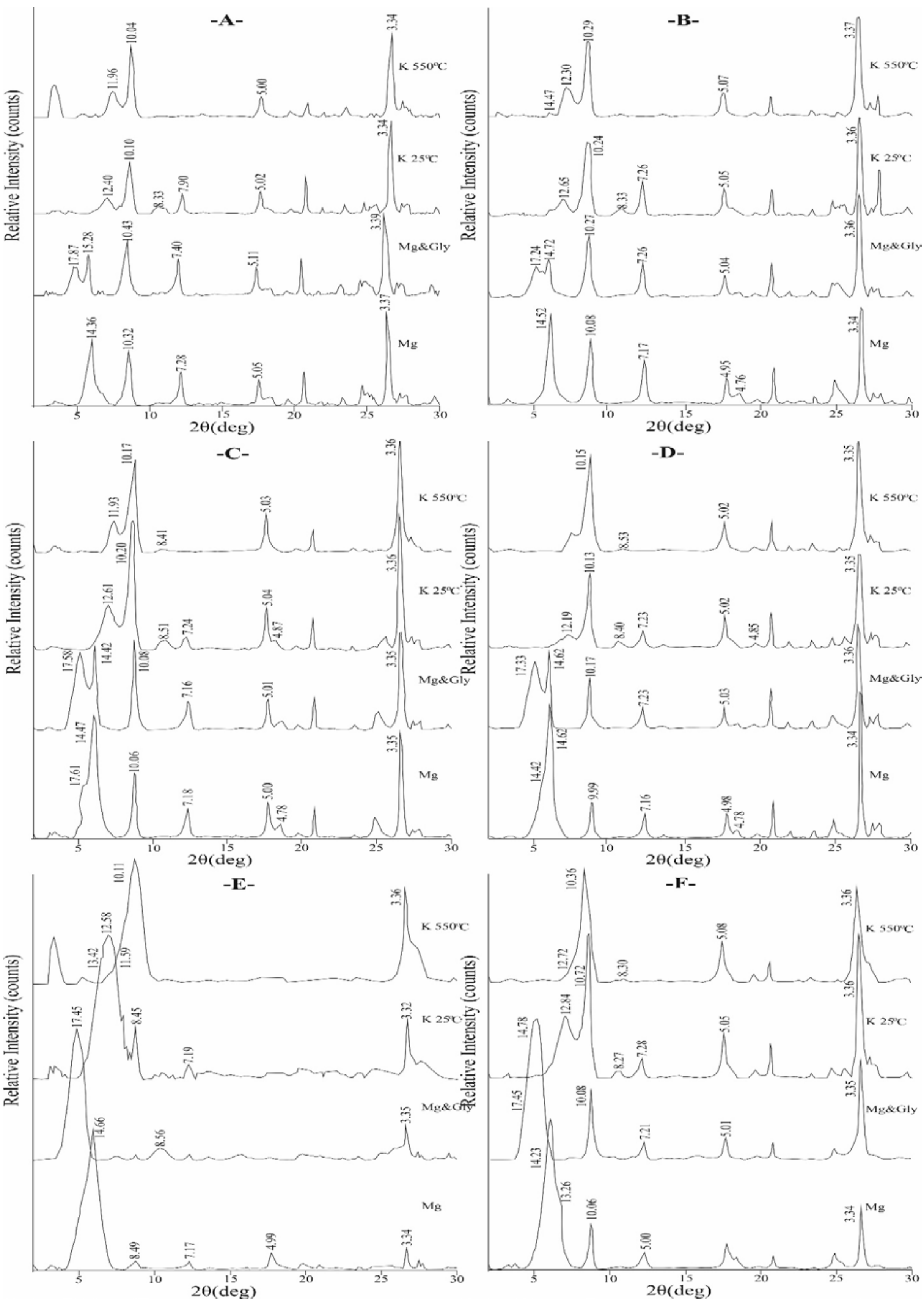

Figure 3. X-ray diffractograms of selected samples A: PI-Ap (0-30 cm), B: PII-Ap (0-23 cm), C: PIII-Ap (0-10 cm), D: PIV-Ap (0-22 cm), E: PV-A (0-19cm), F: PVI-A (0-18 cm)

They supplement the elemental concentration ratios of saprolite and parent bedrock to compensate for 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 Zr. The rates obtained using Zr showed homogenous values, except for Haplic Vertisol, in which Zr/Rb ranged between 1.50 and 11.14.

X-ray diffractograms of selected samples are shown in figure 3. According to X-ray diffractograms of selected samples, phyllosilicates of varying amounts and degrees of crystallization, including kaolinite at 1:1 and various 2:1 minerals, were found to have formed in all six pedons. Smectite was common, whereas vermiculite and zeolite were found only in trace amounts. Peaks for most clay minerals were strong and indicated good crystallization. Mg-saturated clay exhibited three intensity peaks, at 1.44-1.40 nm, 0.95-1.00 nm, and 0.71-0.72 nm. The reflection at 0.72 nm disappeared at 550°C. The 1.4-1.5 nm peak was partially expanded to 1.6-1.5 nm by glycolation and contracted to 1.43-1.20 nm following K saturation at 20°C. An ill-defined diffraction band was observed between 1.0 and 1.1 nm at 550°C, indicating the presence of smectite (Sm), illite (I), kaolinite (K), vermiculite (Vm), and zeolite (Ze). Illite was the most abundant clay mineral in Pedons I, II and III, whereas smectite was the most abundant clay mineral in Pedons IV, V and VI. XRD findings indicated distribution of clay mineral type in surface horizons to vary somewhat by pedon, as follows: Pedon I: illite > kaolinite > smectite > vermiculite>zeolite; Pedon II: illite > smectite > kaolinite > vermiculite > zeolite; Pedon III: illite > smectite > kaolinite > zeolite; Pedon IV: smectite > illite > kaolinite > zeolite; Pedon V: smectite > kaolinite > zeolite; Pedon VI: smectite > illite > kaolinite.

In the study area, the main negative impacts of soil-forming factors on profile development in hillslope positions (shoulder and back slope) are soil erosion and parent material (such as sandstone and hard marl) that is resistant to weathering. 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 a mass movement event. Such interruptions are relatively common on steep slopes, so Lithic Leptosol is often predominant there. Therefore, these soils can be defined as young soils, and that was observed in the present study. On the other hand, soils of lower slope degree (summit, low back, foot slope and flat area), classified as Vertic Cambisol, Oxyaquic Cambisol, Calcaric Cambisol and Chromic Vertisol, showed greater subsurface profile development due to lack of interruption events. The main subsurface diagnostic horizons of these soils are cambic, slickensides, and calcic horizons. The results clearly showed that topographic condition strongly affects soil physicochemical, mineralogical, and morphological properties, either directly or indirectly, in the local region. This was also supported by chemical weathering indices such as CIA, CIW, Base/R_2O_3 (Al_2O_3 + Fe_2O_3 sesquioxide or R_2O_3), and PIA in this study, except for Haplic Vertisol. 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 the weathering of pedons developed on different parent material and located on different topographies. The fact that the physical, chemical, and mineralogical characteristics in the pedons had different variation each other however, the weathering indices of soils determined using geochemical characteristics showed a slightly weathered a along pedons indicates that the pedons show almost similar weathering levels despite their different ages.

4. CONCLUSION

In the research area, the main negative effects of soil forming factor on pedon development in hillslope positions (shoulder and back slope) are soil erosion and parent material (such as basalt, sand stone and hard manl) which is resistance for weathering condition. Mass movement or landslides and soil erosion are important geomorphic processes in hilly or 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 without covering vegetation density, so Lithic Leptosol often predominant there. Therefore, these soils can be described as young soils. This event was observed in this present study. On the other hand, soils in lower slope degree (summit, low back, foot slope and flat area) classified as Vertic Cambisol, Oxyaquic Cambisol, Calcaric Cambisol and Chromic Vertisol showed differences in terms of more development sub surface profile due to no interruption events. Main subsurface diagnostic epipedon of these pedons are cambic, slickensides and calcic horizons. The results clearly showed that topographic condition strongly effects 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/R2O3 (Al2O3 + Fe2O3 ses-quioxide or R2O3) and PIA in this study except for Haplic Vertisol. 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 different parent material and located on different topographies. The fact that the physicochemical, geochemical and mineralogical characteristics in the pedons had different variation each other however, the weathering indexes of pedons determined using geochemical characteristics showed a slightly weathered a along pedons indicates that the pedons show almost similar weathering levels despite their different ages.

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REFERENCES

Aksoy, E., 1991. *Güney doğu Anadolu bölgesindeki petrocalcik horizonlu toprakların önemli özellikleri oluşu ve sınıflandırılması.* Toprak İlmi Derneği 12. bilimsel toplantısı (in Turkish).

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 and Particle Denstity. In: Methods of Soil Analysis, Part I, Phsical and mineralogical Methods.* ASA and SSSA Agronomy Monograph no 9 (2nd ed), Madison. pp: 363-381.

Bouyoucous, G.J., 1951. *A Recalibration of the Hydrometer Method for Making Mechanical Analysis of Soils.* Agronomy Journal 43, 434-438.

Chao, T.T. & Sanzolone, R.F., 1992. *Deco 429 mposition Techniques.* Journal of Geochemical Exploration 106, 44-65.

Davidson, E.A. & Janssens, I.A., 2006. *Temperature sensitiviy of soil carbon decomposition and feedbacks to climate.* Nature 165-173.

Dengiz, O., 2010. *Morphology, Physico-Chemical Properties and Classification of Soils on Terraces of the Tigris River in the South-East Anatolia Region of Turkey.* Journal of Agricultural Sciences 16 (3), 205-212.

Dengiz, O. Sağlam, M., Özaytekin, H.H. & Baskan, O., 2013. *Weathering Rates and Some Physico-Chemical Characteristics Of Soils Developed on A Calcic Toposequences.* Carpathian Journal of Earth and Environmental Sciences 8 (2), 13 – 24.

Duzgoren-Aydin, N.S., Aydin, A. & Malpas, J., 2002. *Re-assessment of chemical weathering indices: case study of pyroclastic rocks of Hong Kong.* Engineering Geology 63, 99-119.

FAO/ISRIC, 2006. *World Referances Base For Soil Resources World Soil Rep.,* No, 103. Rome, 128p.

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.* Geolog 23, 921–924.

Gaillardet, J., Dupré, B., Allegre, C.J. &Négrel, P., 1997. *Chemical and physical denudation in the Amazone River Basin.* Chemical Geology 142, 141 – 173.

Gardner, L.R., 1980. *Mobilization of Al and Ti during rock weathering isovolumetric geochemical evidence.* Chemical Geology 30, 151–165.

Gardner, L.R., Kheoruenromne, I. & Chen, H.S., 1978. *Isovolumetric geochemical investigation of a buried granite saprolite near Columbia, SC, USA.* Geochimica et Cosmochimica Acta 42, 417– 424.

Gardner, L.R., 1992. *Long-term isovolumetric leaching of aluminium rocks during weathering: implications for the genesis of saprolite.* Catena 19, 521–537.

Gee, G.W. & Bauder, J.W., 1986. *Particle-size Analysis. P. 383 - 411. In A.L. Page (ed.). Methods of soil analysis, Part 1, Physical and mineralogical methods.* Second Edition, Agronomy 383-411.

Hamdan, J. & Burnham, C.P., 1996. *The contribution of nutrients from parent material in three deeply weathered soils of Peninsular Malaysia.* Geoderma 74, 219–233.

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

Heimann, M. & Reichstein, M., 2008. *Terrestrial ecosystem carbon Dynamics and climate feedbacks,* Nature 451, 289-292.

Idoga, S., Ibanga, I.J. & Malgwi, W.B., 2006. *Variation in soil morphological and physical properties and their management implication on a toposequence in Samaru Area, Nigeria.* Proceedings of the 31st annual conference of the Soils Science Society of Nigeria. 13-17th Nov. 2006. Zaria.

Jenny, H., 1941. *Factors of Soil Formation: New York,* London, McGraw- Hill Book Company, 281p.

Kabata-Pendias, A. & Pendias, H., 1992. *Trace Elements in Soil and Plants. 2 nd. Edition*, CRC Press, Boca Raton, FL. p.365.

Kibar, M., Deniz, K. & Sarıoğlu, F., 2012. *The Morphology, Mineralogy, Geochemistry and Physical Implications of Foid bearing Syenite and Syenite-Carbonate Rocks Contact Zone Soils: Kırşehir-Akpınar-Buzlukdağ, Turkey.* Eurasian Journal of Soil Science, 1(2), 69 – 74.

Mandel, R.D. & Bettis, E.A., 2001. *Use and Analysis of Soil by Archaelogists and Geoscientists*. In *Earth Sciences and Archaeology*. (P. Goldberg, V.T. Holliday, C.R. Ferring, eds.), New York, Plenum Press, pp. 173-204.

Meybeck, M., 1987. *Global chemical weathering of surficial rocks estimated from river dissolved loads.* American Journal of Soil Science 287, 401 – 428.

McLennan, S.M., 1993. *Weathering and global denudation.* Journal of Geology 101, 295– 303.

Neall, V.E., 1977. *Genesis and weathering of andosols in Taranaki, New Zealand.* Soil Science 123, 400-408.

Nelson, D.W. & Sommers, L.E., 1982. *Total carbon, organic carbon and organic matter.* In: *Methods of Soil Analysis, Part 2. Chemical and Microbiological Methods Page.* (L.A. Miller, R.H. Keeney, D.R, 2 nd eds.). American Society of Agronomy, Madison, WI, 539-579.

Nesbitt, Y.W. & Young, G.M., 1982. *Early Proterozoic climates and plate motions inferred from major element chemistry of lutites.* Nature 299, 715-717.

Oliva, P., Viers, J. & Dupre, B., 2003. *Chemical weathering laws in granitic crystalline environment.* Chemical Geology 202, 223-254.

Özaytekin, H.H. & Karakaplan, S. M., 2012. *Soil formation on the Karadağ volcano at a semi arid environment from the Central Anatolia.* African Journal of Agricultural Research Vol. 7(15), pp: 2283-2296.

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

Pope, G.A., Meierding, T.C. & Paradise, T.R., 2002. *Geomorphology's role in the study of weathering of cultural Stone. Geomorphology 47,211-225*.

Price, J.R. & 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., 1950. *A Survey of Weathering Processes and Products*, University of New Mexico Press, Albuquerque, p.95

Ruxton, B.P., 1968. *Measures of the degree of chemical weathering of rocks.* Journal of Geology 76, 518–527.

Roaldset, E., 1972. *Mineralogy and Geochemistry of Quaternary Clays in the Numedal Area, South Norway.* Norsk Geolisk Tidsskrift 52, 335-369.

Schaetzl, R. & Anderson, S., 2005. *Soil Genesis and Geomorphology,* ISBN-10 0-521-81201-1.

Shao, J., Yang, S. & Li, C., 2012. *Chemical indices (CIA and WIP) as proxies for integrated chemical weathering in China: Inferences from analysis of fluvial sediments,* Sedimentary Geology, 265-266, pp.110-120.

Soil Survey Manual., 1993. *Soil Survey Manual.* USDA Handbook No 18.

Soil Survey Staff., 1999. *Soil Taxonomy. A Basic System of Soil Classification for Making and interpreting Soil Survey.* USDA agriculture Handbook No 436 Washington D.C.

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

Taylor, S.R. & McLennan, S.M., 1985. *The Continental Crust: its Composition and Evolution.* Blackwell, Oxford, p.312.

Vogt, T., 1927. *Sulitjelmafeltets geologiog petrografi.* Norges Geologiske Undersokelse, 121, 1-560 (in Norwegian, with English).

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

Whittig, L.D. & Allardice, W.R., 1986. *X-ray diffraction techniques.* In*: Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods*. (A. Klute, ed., 2nd eds.), ASA publication 9, Madison, Wisconsin, 55-86.

Wood, D.A., Joron, J.L. & Treuil, M., 1979. *A re-appraisal of the use of trace elements to classify and discriminate between magma series erupted in different tectonic settings.* Earth and Planetary Science Letters. 45, 326-336.

Yatsu, E., 1988. *The nature of weathering an introduction*. Tokyo, Sozosha.

Zhang, Gan-Lin., Pan Ji-Hua, Huang, Cheng-Min & Gong, Zi-Tong., 2007. *Geochemical Features of a Soil Chronosequence Developed on Basalt in Hainan Island, China.* Revista Mexicana de Ciencias Geológicas 24 (2), 261-269.

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