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Assessment of Biogeochemical–Mineralogical Characteristic and Weathering Indices of Soils Developed on Basaltic Parent Material and Toposequence Under Subhumid Ecosystem

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ABSTRACT

Especially in local areas, the formation of different soils on the same parent material is closely related to the topographic position, which has an important effect on the morphological, mineralogical, biological, and weathering processes of soils. Because, topography affects the distancing of water and other materials from the soil or addition of soil. Besides mineralogical and geochemical events occurring due to topographic change in soils with different development levels on basalt parent material under semitemperate ecological conditions, the purpose of this study is to examine the changes in the biological properties of soils with microbial biodiversity that affect these changes. For this purpose, six soil profiles representing high land plateau, high land back slope, low land plateau, low land back slope, toe slope, and foot slope were examined, which show distribution on the section in the South–North direction on basalt parent material of Engiz Çayı Basin, Turkey. Since soils formed on high slope land have poor profile development, they are described as young soils and classified in the Entisolls, and others are classified in Inceptisol and Vertisolls according to their horizon developments. pH values of surface horizons of all profiles range between 6.74 and 8.28, while organic matter values range from 1.54 to 3.53%. Although the dominant clay mineral is Smectite especially in surface soils, kaolinite clay mineral is also available in Entisol soils. Soil weathering rates are generally between very little weathering and moderate weathering, and Base/R_2O_3 values are determined between 0.5 and 1.3. Besides, it was determined that fungi has the most diversity among microorganisms of soil formed on basalt and actinobacterium varieties have the most diversity according to bacillus groups. Moreover, in this study, it has been determined that the isolated *Actinobacteria* members have gene regions that synthesize molecules called siderophores. This case has also been proposed as evidence that *Actinobacteria* members contribute to soil formation processes.

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Actinobacteria; geo-biochemical evolution; soil formation; sub-humid ecosystem weathering index; toposequence

Introduction

The time taken for soil formation affects the properties of soils and this determines their weathering rates. This effect occurs in time due to events such as the change of physical, chemical, biological, and mineralogical properties or variation of horizons in different numbers. While the chemical structure of the soil is controlled by the parent material in the early stages of the formation, the chemical properties of mature soils reflect the effects of the weathering medium. Soil composition with pedogenic processes, which emerge in time with the effect of vegetation, topography, organisms, and especially the climate, differs from the parent material. Initially, this differentiation emerges as redistribution of elements in horizonization process in the soil profile and lastly emerges as the differentiation of soil types depending on this distribution in the landscape (Jenkins and Jones 1980). However, although the time for soil formation is the same, soil morphology and bio-physico-chemical properties may differ with the effect of other soil-formation factors. Therefore, it is quite challenging to predict the soil formation factors accurately.

According to Soil Survey Division Staff (1993), it was reported that during the study of soils in local areas, topography or relief can be used to clearly see the effect of parent material and time on the soil. Moreover, it was stated by the researchers that topography is an important factor to change the effects of climate, natural vegetation, and time in soil formation and its contribution to the formation of soil arises from the drainage of the first-degree surface slope and flow of water from the surface of the land, hence the amount that can leak into the soil profile and its effects on the degree of erosion. It was also reported by many researchers that the second-degree effect of topography is due to differences in the directions against the sun and wind, the topography may be an important cause of local soil changes, a

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significant change in topography may cause the formation of different soils even if the climatic conditions are the same in a region (Abate and Kibret 2016; Alijani and Sarmadian 2014; Dengiz and Şenol 2018).

Since the soil formation is very slow progress, its observation is limited to one or few events on the surface. However, it is possible to examine and establish relationships between the factors that form soil. In other words, maturation of soils can be estimated by determining the changes in physical, chemical, and mineralogical properties. Soils have another role in the biochemical cycle of nutrients and carbon (C). Moreover, since silicate minerals are broken down and transform into carbonate, it is also important in terms of C control in the atmosphere in the long term (Berner et al. 1989). Chemical weathering is a continuous and dynamic geochemical process and it is a factor that determines the availability of plant nutrients and the chemical status of soils in the long term (Duan et al. 2002).

The principle of soil formation is based on the distancing of alkaline and soil alkaline cations during the degradation of silicate fractions. Loss of basic cations by leaching and plant intake depends on the mineral weathering mechanism. Souri et al. (2006) reported that if weathering does not cover losses, plant nutrient deficiency occurs, and the soil becomes acidic. Soil formation, weathering rate, and their process are strongly affected by the climate. In addition to that, Dahlgren et al. (1999) and Birkeland (1999) stated that precipitation and temperature belong to the most important factors that determine the type and amount of chemical, physical, and biological weathering.

Along with the environmental conditions such as pH, temperature, and humidity, the heterogeneity of the rocks have a great influence on the number, types, and activities of microorganisms in weathering of rocks by microorganisms (Bland and Rolls 1995; Santelli et al. 2010; Taylor and Taylor 2000). Because minerals available in rocks provide an important nutritional source for microorganisms. For instance, some researchers reported that rocks containing some minerals such as biotite and hornblende cause faster weathering when compared to rocks containing minerals such as feldspar, quartz, which are poor in nutrients (Le Roux et al. 2008). Similarly, Tang et al. (2010) state that endolytic bacteria play an important role in the formation of karst soils on dolomite and limestone. In addition to organic and inorganic acids created by microorganisms as a result of their metabolic activities, Bin et al. (2008), reported that weathering of limestone occurs due to effects of extracellular polysaccharides increasing the solubility of calcium carbonate as a result of the effects of extracellular polysaccharides.

Microorganisms are important because of the decomposition of plant nutrients from rocks and minerals. Besides macro creatures living in the soil, microorganisms play an important role in the breakdown of organic materials and mineral rocks, and these creatures sometimes contribute soil formation by breaking down rocks and minerals by causing mechanical and chemical effects. It has been shown in previous studies that bacteria commonly found in rocky habitats are members of *Actinobacteria*, *Proteobacteria*, and *Bacteroides* and it was reported that actinobacteria are among important groups in endolytic habitats (Cockell et al. 2009). Also, in the study of Stranghoener et al. (2018), which was conducted in the laboratory by using biotic (microorganism) and abiotic factors to investigate the potential role of microorganisms in alteration and Fe mobilization in different natural basalts, it was found that unlike abiotic samples, in some of the biotic samples, pH decreases to 4.5–5.5 levels from neutral at 30 °C and then approaches back to neutral, and remained acidic at 5.5 at 8 °C. On the other hand, significant amounts of dissolved Fe were detected in all biotic experiments. Besides, it was observed that microorganisms begin attacking the rock and synthetic basaltic rocks by lowering the pH to obtain the necessary nutrients and thus increase the dissolution rate when microorganisms cannot obtain nutrients from the solution in biotic conditions. Dissolved Fe and Al measured only in biotic colonization experiments and dissolved Fe and Al concentrations also increased. Moreover, a network of fine cracks was also observed below the surface of basaltic rocks in biotic experiments. Accordingly, it was determined that microorganisms can supply essential nutrients by themselves by dissolving basic rocks in biotic experimental medium and cells are preferably attached to the surfaces of natural basaltic rocks containing beneficial nutrients (Stranghoener et al. 2018).

Bacteria are also crucial for the creation of plant nutrients, which are very important both in terms of soil and nutrition of plants, from rocks-minerals (Jonasson et al. 1996). It has been found that microbial oxidation of Fe^{2+} by different strains of iron-oxidizing bacteria (FeOB) increases the weathering of basaltic rocks six to eight times compared to abiotic rates (Edwards et al. 2004). In nature, Fe is available in two oxidant states as Fe^{2+} and Fe^{3+}. In neutral pH and oxygen-rich mediums, Fe is mostly found as insoluble Fe^{3+}, which forms Fe oxy (hydroxides). Moreover, microorganisms develop strategies to overcome this problem by creating reactive micro-mediums on the mineral or glass surface. The most important of these strategies are; (i) complexation or oxidation/reduction of ions that change the balance of the system (Navarrete et al. 2013; Stockmann et al. 2012), and (ii) increase of the dissolution and release of limiting nutrients with bacterial acid production that changes the pH of the solution and proton consumption (Fe, P, etc.) (Wu et al. 2007). In their study, Perez et al. (2016) found that Fe variation in the basaltic parent material (Fe^{2+}, Fe^{3+}, and Fe (hydroxy) oxides) may affect the production of siderophore. Siderophores are high affinity Fe^{3+} binding agents, which have small molecule structures and are produced by some bacterial groups and actinobacteria (Kannahi and Senbagam 2014). Many endolytic actinobacteria, including *Actinomadura*, *Actinopolyspora*, *Kibdelosporangium*, *Micromonospora*, *Nocardia*, *Pseudonocardia*, *Salinispora*, and *Streptomyces* produce siderophores (Macagnan et al. 2008; Singh et al. 2014; Verma et al. 2016). Nakouti and Hobbs (2013) observed that a siderophore, that can separate a wide variety of ions including Mn, Co, Cd, Ni, Al, Li, Cu, Zn, and Mg, was synthesized in high amounts by Streptomyces members.

By considering weathering indices, geochemical-chemical events, and mineralogical data occurring due to topographic change in soils with different development levels on basalt parent material under semihumid ecological conditions, this study was performed as a pedogenetical assessment. The second purpose of the present study is to investigate the changes in the biological properties of soils with microbial biodiversity that affects these changes.

Material and method

Site description

The current study was carried out throughout a transverse section in Engiz basin located between Bafra Plain and Canik Mountain which is around 20 km west of Samsun Province in the central Black Sea Region of Turkey (Figure 1) and situated at coordinates between 4597065 N – 253437 E and 4595005 N – 251693 E (UTM-37N Zone/WGS-84, m).

Elevation of this study area extended from 10 m to 300 m a.m.s.l (above mean sea level) and contains four distinct landscape features (foot slope, back slope, lowland plateau, and shoulder) that represent the changes in geomorphology, topographical gradient, parent material, and soil characteristics. The underlying bedrock is primarily made up of Quaternary basaltic colluvial deposits on the foot slope and lowland plateau, and Mesozoic basalt and marl-limestone and on the back slope and highland plateau, respectively. The region is under semihumid climate conditions in which summers are warmer than winters (mean monthly temperature in July is 22.2 °C, and in January 6.9 °C). The mean annual temperature is 13.6 °C, 764.3 mm of precipitation, and evapotranspiration is 726.7 mm $year^{-1}$ (TSMS 2020). The soil temperature regime is classified as mesic, and the moisture regime is ustic (Soil Survey Staff 1999). Pasture and forests are the dominant land covers. A small part of the study area is made up of a slightly sloped (0.0–2.0%) low plateau, whereas mountainous areas, and areas sloping at angles that range from moderate to severe (3–20%), are prevalent in other regions. Only a limited region of the foot slope and lowland plateau is suitable for agricultural management.

Soil sampling

The study area is located within the Engiz Çayı Basin. Hypothesis perspective in this study aimed to reveal the soil formation processes, determination of physical, chemical, morphological, mineralogical, and biological properties of soils formed on basaltic parent material that is located in different topographic positions (high land plateau, toe slope, foot slope, etc.). Besides, comparative chemical weathering rates of soils formed on a toposequences in semi-humid climatic conditions are tried to be revealed by applying the geochemical approach using concentrations of parent and

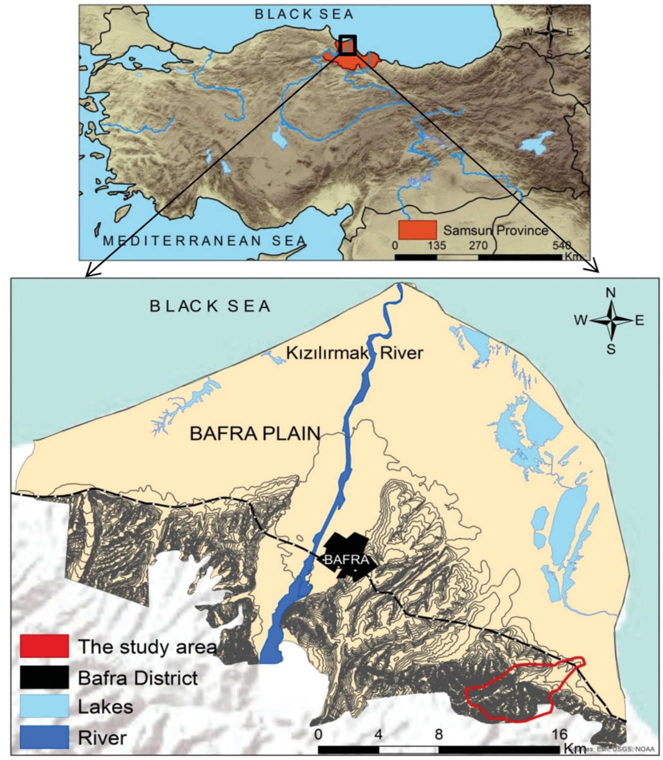

Figure 1. Location map of the study area.

rare soil elements in determining the weathering levels of soils in these different topographic positions.

Topographic scaled 1:5.000 map was used by digitizing in the GIS to create transect shape, elevation, slope, and relief maps of the study area. Six soil profiles representing high land plateau, high land back slope, low land plateau, low land back slope, toe slope, and foot slope were created, which show distribution on the section in the South–North direction on basalt parent material of Engiz Çay Basin, and their schematic representation is given in Figure 2.

The morphological features of the six profiles in the field were determined, followed by sample collection using genetic horizons and classification in compliance with Soil Taxonomy (Soil Survey Staff 2014) and IUSS Working Group WRB (2015). To investigate the physical, chemical, and mineralogical characteristics of the soil, fourteen disturbed and fourteen undisturbed soil samples were collected. Then, for laboratory analysis, the samples were firstly 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 sulfate 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 (calgon) (Gee and Bauder 1986). Bulk density (Blake and Hartge 1986) was determined from undisturbed samples. Organic matter was determined in air-dry samples using the Walkley-Black wet digestion method (Nelson and Sommer 1982), soil reaction-pH and EC-electrical conductivity (of the saturation) by method of the Soil Survey Laboratory (2004) and lime content ($CaCO_3$%) by Scheibler calcimeter (Soil Survey Division Staff 1993). Exchangeable

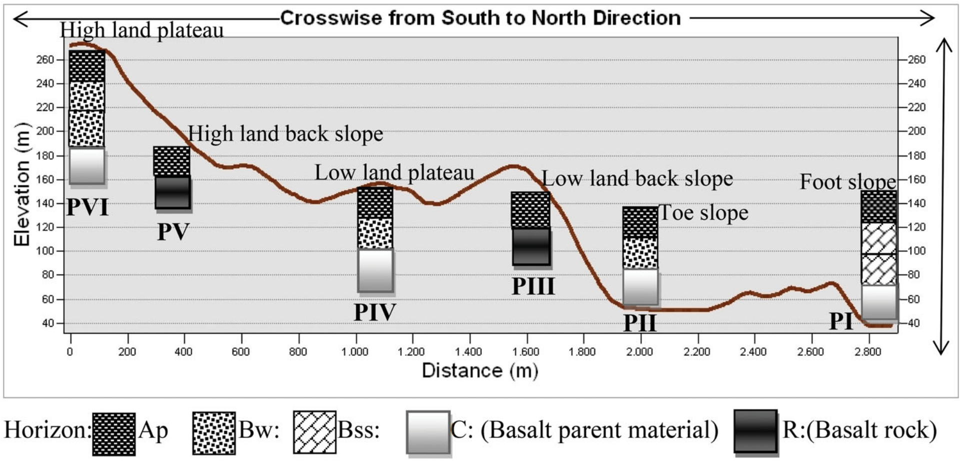

Figure 2. Transect of the six different soil pedons on basalt parent material and toposequence.

cations and cation exchange capacities (CEC) were measured using a 1 N NH4OAc (pH 7) method (Soil Survey Laboratory 2004).

Calculation of weathering indices. Several various indices have been developed and proposed to define the weathering status in soils (Harnois 1988; Nesbitt and Young 1982). In this context, the basic principles upon which all indices are based on is determined by the varying ratios of some basic cations (Ca, Mg, K, and Na) to acidic cations of Al and Si. In this study, the following indices were used to quantify the weathering rates of the profiles:

a. Chemical Index of Alteration (CIA) (Nesbitt and Young 1982):

$$CIA = (100)\left[Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O)\right]$$

b. Chemical Index of Weathering (CIW) (Harnois 1988):

$$CIW = (100)\ [Al_2O_3/(Al_2O_3 + CaO + Na_2O)]$$

c. Basic cations/R_2O_3 ratio (Birkeland 1999):

$$\text{Basic cations}/R_2O_3 = (MgO + CaO + Na_2O + K_2O)/(TiO_2 + Fe_2O_3 + Al_2O_3)$$

Clay mineralogy. In order to determine clay mineralogy of the soil profiles, soil samples were collected from surface and subsurface horizons of each profile. Following the degradation of organic matter with dilute and Na–acetate-buffered H_2O_2 (pH 5), the clay fraction (<2µm) was determined using soil dispersion with a sodium hexamephosphate (calgon) and sedimentation in water. Cu Kα radiation at an angle of 2θ ranging from 2° to 30°, with steps of 0.02° 2θ and a counting time of 2 seconds per step, specimens oriented on glass slides were analyzed with X-ray diffraction (XRD). Then, Mg and K saturation, along with ethylene glycol solvation (EG) methods were applied, respectively, followed by heating at 550 °C for 2 h. The minerals and their relative abundances were determined using the diagnostic XRD spacing of the minerals, and then evaluated using their XRD relative peak intensities obtained from the XRD graphs (Whittig and Allardice 1986). Selected soil samples were also used for scanning electron microscope (SEM) analysis. These samples were mounted onto aluminum stubs and coated first with carbon and then with gold. This double coating proved superior to a coating of carbon or gold alone. Each specimen was studied at magnifications ranging from 250 to 20.000.

Isolation and selection of microorganisms. Soil samples were selected from the surface and sub-surface horizons for each profile represented for actinobacterial microorganism isolation and strain selection. These soil samples were collected under sterile conditions, put in sterile bags, and brought to the laboratory. In the study laboratory, each soil sample was transferred to sterile petri dishes and allowed to dry for 15 days. At the end of this period, soil samples were ready for cultivation studies. Cultivation studies were carried out in 8 different growth cultures by using the dilution plate technique (Waksman 1927) to selectively isolate actinobacteria from soil samples. Cultivation of soil-ringer solution (0.2 ml), which is taken from 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4} dilutions with the help of automatic pipette was performed, on different growth culture such as Czapek-Dox Agar (Weyland 1969), Bennett's Agar (Jones 1949), Glycerol-asparagine Agar (Pridham et al. 1957), Rafinoz-Histidin Agar (Vickers et al. 1984), Starch-Casein Agar (Küster and Williams, 1964), Humic Acid-Vitamin Agar (Hayakawa and Nonomura 1987), SM1 Agar (Tan et al. 2006), SM2 Agar (Tan et al. 2006) and SM3 Agar (Tan et al. 2006) where antibiotics such as cycloheximide, rifampicin, nystatin, novobiocin, neomycin, and nalidixic acid were added. Actinobacterium and similar colonies developing at 28 °C and 14-21 days incubation in the selective isolation culture medium were transferred to glucose yeast extract agar supplemented with cycloheximide (50 g/mL^{-1}) (GYEA; Gordon and Mihm 1962), tryptone yeast glucose extract agar (TYGA; Bower and Hucker 1930) and NZ-Amin agar surface by using sterile toothpicks. Pure isolates were obtained from the transferred plates after 14 days of incubation at 28 °C. After completing genomic DNA isolation of pure cultured strains, PCR amplification of the 16S rRNA gene region was carried out. The sequencing process of PCR amplification products was carried out by Macrogen Inc. (South Korea) company. 16S rDNA sequence data obtained was aligned in ChromasPro Version 1.7.6 (Technelysium Pty Ltd) and the 16S rDNA sequence similarity of the isolates with the closest relative organisms was determined with the global alignment algorithms on the server EzTaxon (URL-13: http://www.ezbiocloud.net/eztaxon; Kim et al. 2012). Whole-genome analysis of *Actinomadura* sp. strain 14C53 and *Nonomuraea basaltis* 160415^T defined a first novel actinobacteria species from this project are carried out in RAST server (Brettin et al. 2015) and AntiSMASH (Weber et al. 2015) bacterial version application.

Results and discussion

Physico-chemical and morphological features of the representative pedons

Physico-chemical and morphological properties of soils do not only vary in wide geographical areas but also in local areas as a result of dynamic interactions of environmental factors such as topography, climate, geological material, and vegetation of the environment in which they form (Dengiz et al. 2013a; Tunçay et al. 2020). Representative topographic positions (high land plateau, high land back slope, low land plateau, low land back slope, toe slope, and foot slope) and elevations of six different profiles opened in different topographic positions on the basalt rock in the north-south direction are shown on the cross-section diagram in Figure 2 and morphological and physico-chemical analysis results of these profiles are given in Tables 1 and 2.

Profile coded as PI and located on foot slope positions in the North-South direction is formed on flat sloping and deep soils. The entire profile has clay texture and clay content ranges from 56.2 to 78.2%. Although CEC surface soil is 42.80 cmol kg^{-1} due to the amount of organic matter and clay content, this amount decreases with increasing depth. This case also applies to organic matter content and although it is 1.65% in the surface horizon, it decreases to 0.14% after 65 cm depth. Dominant spectral color in the profile's genetic horizons is 2.5 Y and darkening occurs in the parent material and it becomes 10YR. While strong granular structure (3 mgr) formation occurs in the surface horizon, a strong subangular blocky (3msbk) structure is formed in the subsurface horizons. Soil reaction is slightly alkaline and pH values range from 7.05 to 8.25. $CaCO_3$ is very low in the profile and although it is 0.20% on the surface, it slightly increases in depth and reaches 2.67%. The dominant exchangeable cations in the soils are Ca and Mg ions. Salinity and alkalinity problems are not detected in soils. In addition, it was observed that there were cracks 1−5 cm in width at the surface of this soil in dry seasons and slickenside in the profile. Based on these indicators, the soil was classified as Typic Haplustert according Soil Taxonomy (Soil Survey Staff 2014) and as Haplic Vertisol according to IUSS Working Group WRB (2015) classification.

Soil profile (PII) formed on toe slope position has moderate depth and heavy texture in genetic horizons. Clay content varies between 58.3 and 61.9% up to 66 cm depth. The horizon orders in PII were defined as Ap-Bw-2Cr. It was found that CEC is 43.70 cmol kg^{-1} in surface horizon. On the other hand, this amount decreases to 22.77 cmol kg^{-1} after 66 cm depth. This case can be explained due to the decrease of organic matter and clay content. At the same manner, this is also true for distribution of organic matter content in profile and although it is 2.21% on the surface,

Table 1. Chemical properties and classification Soil Taxonomy (2014)/IUSS Working Group WRB (2015) of profiles on transect.

Horizon	Depth (cm)	pH	EC dS m^{-1}	$CaCO_3$ %	OM%	CEC kg^{-1}	Exchangeable cations cmol kg^{-1}		
							Na^+	K^+	Ca^{++}+Mg^{++}
PI/foot slope/25 m (Typic Haplustert/Haplic Vertisol)									
Ap	0–23	7.50	0.17	0.20	1.65	42.8	0.22	1.67	40.91
Bss1	23–65	7.30	0.44	0.98	1.26	41.4	0.25	1.47	39.64
Bss2	65–106	8.25	0.17	1.10	1.09	40.3	1.33	1.41	37.59
C	106 +	8.14	0.11	2.67	0.14	39.9	1.35	1.40	36.04
PII/toe slope/50 m (Vertic Haplustept/Vertic Cambisol)									
Ap	0–15	8.28	0.26	0.79	2.21	43.7	0.36	0.36	42.97
Bw	15–66	8.12	0.18	1.26	0.67	43.4	0.47	0.32	42.58
2Cr	66–106	8.20	0.25	1.75	0.55	27.8	1.02	0.26	26.49
PIII/low land back slope/132 m (Lithic Ustorthent/Eutric Regosol)									
A	0–19	7.89	0.40	0.39	3.37	41.9	0.16	0.49	41.02
R	19–32	—	—	—		—	—	—	—
PIV/low land plateau/160 m (Typic Haplustept/Lithic Cambisol)									
A	0–18	7.06	0.44	1.08	1.88	47.3	0.24	0.32	46.71
Bw	18–57	7.31	0.42	1.02	0.06	50.5	0.34	0.09	50.11
Cr	57–87	7.01	0.51	0.39	0.57	40.5	0.58	0.09	39.87
PV/high land back slope/190 m (Lithic Ustorthent/Eutric Regosol)									
A	0–11	6.74	0.35	0.09	1.54	28.7	0.35	0.43	27.92
Cr	11–65	7.01	0.20	0.29	0.87	17.7	0.54	0.12	17.00
PVI/high land plateau/251 m (Vertic Haplustept/Vertic Cambisol)									
A	0–12	7.14	0.55	0.69	3.53	49.7	0.29	0.58	48.85
Bw1	12–41	7.70	0.54	0.98	1.78	44.6	0.27	0.31	43.98
Bw2	41–84	7.92	0.11	0.98	1.41	52.6	0.64	0.29	51.62
2Ck	84–105	7.94	0.38	6.37	1.29	44.5	0.63	0.09	43.74

Table 2. Morphological, physical properties, and classification Soil Taxonomy (2014)/IUSS Working Group WRB (2015) of profiles on transect.

Horizon	Depth (cm)	Color		Texture				BD g cm^{-3}	Structure/boundary
		Dry	Moisture	C	Si	S	Class		
PI/foot slope/25 m (Typic Haplustert/Haplic Vertisol)									
Ap	0–23	2.5Y 5/2	2.5Y 3/3	56.2	23.1	20.7	C	1.45	3mgr/aw
Bss1	23–65	2.5Y 5/3	2.5Y 3/2	62.6	12.8	24.5	C	1.57	3msbk/cs
Bss2	65–106	2.5Y 5/2	2.5Y 4/1	68.4	15.8	15.8	C	1.45	3msbk/gd
C	106 +	10 YR 6/1	10YR 4/2	78.4	2.8	18.8	C	—	mas
PII/toe slope/50 m (Vertic Haplustept/Vertic Cambisol)									
Ap	0–15	2.5Y 5/2	2.5Y 3/2	58.3	20.0	21.7	C	1.52	3mgr/as
Bw	15–66	10YR 5/3	10YR 4/3	61.9	25.6	12.5	C	1.58	3csbk/cw
2Cr	66–106	10YR 5/4	10YR 4/3	37.3	34.8	27.9	CL	—	mas
PIII/low land back slope /132 m (Lithic Ustorthent/Eutric Regosol)									
A	0–19	2.5Y 4/3	2.5Y 3/3	32.5	18.6	48.9	SCL	1.46	1fgra/aw
R	19–32	—	—	—	—	—	—	—	—
PIV/low land plateau/160 m (Typic Haplustept/Lithic Cambisol)									
A	0–18	10YR 4/3	10YR 3/3	54.4	22.6	23.1	C	1.54	2mgr/as
Bw	18–57	10YR 4/3	10YR 4/4	61.1	17.7	21.2	C	1.45	3csbk/cw
Cr	57–87	10YR 4/3	10YR 3/3	57.5	22.6	19.9	C	—	mas
PV/high land back slope/190 m (Lithic Ustorthent/Eutric Regosol)									
A	0–11	2.5Y 5/2	2.5Y 3/1	22.0	21.8	56.2	SL	1.56	1wgr/aw
Cr	11–65	2.5Y 5/3	2.5Y 3/3	14.6	9.3	76.1	LS	—	sg
PVI/high land plateau/251 m (Vertic Haplustept/Vertic Cambisol)									
A	0–12	2.5Y 5/3	2.5Y 3/3	61.9	23.6	14.5	C	1.56	3cgr/as
Bw1	12–41	2.5Y 5/3	2.5Y 4/3	49.9	27.7	12.5	C	1.50	2msbk/gd
Bw2	41–84	2.5Y 6/3	2.5Y 4/3	47.9	32.3	19.8	C	1.66	2mabk/cw
2Ck	84–105	5Y 8/1	5Y 8/2	40.0	40.8	19.1	C	—	mas

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. Boundary: a: abrupt; c: clear; g: gradual; d: diffuse; s: smooth; w: wavy; i: irregular; C: clay; BD: bulk density; Si: silt; S: sand.

this ratio decreases to 0.55% in the subsurface layer. Soil reaction is alkaline and pH values range from 8.12 to 8.28. Secondary $CaCO_3$ content is very low in the entire profile and it slightly changes from surface to parent material due to leaching and accumulation process. This profile was classified as Vertic Haplustept (Soil Survey Staff 2014)/Vertic Cambisol (IUSS Working Group WRB 2015) since it has vertic property on surface and cambic epipedon in profile.

Since the surface is covered by very weak vegetation and due to steep slope, profile coded PIII located at 135 m a. m. s. l. and developed on the low land back slope position on the North–South direction has erosion problem and therefore this soil has very shallow depth (19 cm). That's why, it can be said that slope is one of the most important factors controlling the pedogenic process on P III. The surface soil is of mostly coarse texture, its class is sandy clay loam. CEC and organic matter contents are 41.85 cmol kg^{-1} and 3.37% in surface horizon, respectively. Soil reaction is slightly alkaline, and pH value is 7.89. $CaCO_3$ content is very low in the profile (0.39%). There are no diagnostic horizons except for ochric A horizon. There is only a weak granular structure (1fgra) development in the surface horizon. This profile is described as young soil since it does not have a sub-surface diagnostic or epipedon horizon and contains a lithic contact within 50 cm, so it was classified as Lithic Ustorthent/Eutric Regosol.

PIV pedogeneticaly formed on the low land plateau and located 160 m a. m. s. l is deep soil with a slight slope degree. Clay is the dominant texture in PIV and clay content in the profile ranges from 54.4 to 61.1%. Its CEC values also range from 40.54 to 50.54 cmol.kg^{-1}. While the amount of organic matter is 1.88% on the surface, this rate decreases rapidly in subsurface horizons. Soil reaction is slightly alkaline and pH values vary between 7.01 and 7.31. The dominant color in the entire profile ranges from 10YR 3/3 to 10YR 4/4. Lime is very low in the profile and while it is 0.39% on the surface as a result of the leaching process, it slightly increases in depth and reaches 1.08%. The main diagnostic horizon was the cambic horizon developed in the structural formation of this profile. Structural development was mostly noticeable between 18 and 57 cm. In addition, due to clay accumulation in cambic horizon, strong subangular blocky (3csbk) structure was shaped and it is classified as Typic Haplustept/Lithic Cambisol.

Soil symbolized as PV is 190 m a. m. s. l. on its section in the North-South direction and on the high land back slope. Dengiz (2010) reported that slope contributes to greater runoff, as well as to greater translocation of surface materials down the slope through surface erosion and movement of soil. Therefore, this soil has a very shallow depth (11 cm) and sandy loam texture. Since clay and organic matter contents are at very low levels when compared to other profiles, it has low CEC value ranging from 17.66 to 28.70 cmol kg^{-1}. Soil reaction is changing between neutral and slightly acid. Lime content is the lowest in all other selected profiles and it is between 0.09 and 0.29%. Similar with the PII profile, the most important problem of this soil is erosion and shallow depth. Therefore, it was classified as Lithic Ustorthent/Eutric Regosol since it does not include any subsurface diagnostic horizons and contain lithic contacts.

The PVI located at the highest elevation (251 m) from the sea level on the North–South section is developed on the high land plateau position. The entire profile has clay texture and clay content ranges from 40.0 to 61.9%. In this soil, reaction is also slightly alkaline and pH values vary between 7.14 and 7.94. Secondary $CaCO_3$ content is very low in the profile and while it is 0.69% on the surface, it rapidly increases in depth and reaches 6.37%. This leads to the color change of the horizons and while it is 2.5Y 5/3 on the surface and subsurface horizons, it becomes maximum light color (5Y 8/1) on parent material (Ck) due to leaching-accumulation calcium carbonate processes. Besides, some secondary $CaCO_3$ nodules and myceliums were also identified in Ck horizon. Dengiz and Şenol (2018) reported that there are four reasons for secondary $CaCO_3$ on basaltic parent material. One of them is mineral in basalt which includes Ca such as plagioclase to form $CaCO_3$ in the appropriate environmental condition. Similar result has been reported by Tunçay and Dengiz (2016). They investigated chemical weathering rates and geochemical-mineralogical characteristics of soils developed on heterogeneous parent material and toposequence. According to their results, they detected also secondary $CaCO_3$ nodules and myceliums about 2.3–7.1% in soil profile although its parent material is basalt rock. As in PII, this profile is classified as Vertic Haplustept (Soil Survey Staff 2014) since it shows vertic properties on the cambic horizon surface and as Vertic Cambisol according to IUSS Working Group WBR (2015) classification.

Geochemical features and clay mineralogy

SiO_2 content in profiles on the South-North transect in Engiz Çayı basin is above 45% in almost all of them. Si and Al oxide ratios were found more in mature soils with high clay content (Typic Haplustept, Vertic Haplustept, and Typic Haplustert) (Table 3). Although profiles do not show significant change in terms of Fe oxides in all soils, they have the lowest level in the soil (PI) found on the foot slope land, and this amount was determined to be slightly high in the profiles in higher positions. SiO_2 ratio tends to decrease with depth in profiles on gently sloped land but Al does not show a significant increasing or decreasing trend. Al concentration does not vary significantly between the parent material in the profiles and their genetic horizons and this can be the proof that soil formation factors affect the parent material to a limited extent and this trend occurred with the inclusion of parent material. Already, Delvaux et al. (1989) reported that Al_2O_3 concentrations are significantly higher than the amounts reported in our study in Oxisols where soil formation factors are highly effective. While Ca and Mg oxides are dominant in basic oxides, these are followed by K and Na ions. The highest CaO content was detected in 2Ck horizon of Vertic Haplustept coded as PVI situated on the high land plateau position. On the other hand, iron, aluminum, and silicium oxide values are at the lowest level. Except for the PI profile, no significant accumulation tendency is observed in other profiles. P_2O_5 and MnO do not show much change in profiles and ranges between 0.1 and 0.4% and 0.1 and 0.4%, respectively. TiO_2 was determined between 0.4 and 1.1% and regular trend of variation between horizons has not been observed. In general, achieving values close to the parent material in a way that supports weathering in profiles reveals that weathering progresses slowly in soil formation and gaining, loss, intra-profile transportation, and modification are very low. Besides, the fact that TiO_2, which is an important data source in the detection of weathering process, remains in very low values in percentage and there is no difference in soil depth. Hence, this case is also another indicator that reveals the poor pedogenic development. In addition to above information, the chemical content of horizons for each profile was also compared with multiple comparison tests and significance levels were obtained. In the study, TUKEY, MINITAB 16 package program were used for multiple comparison tests and given in Table 3. In statistically significant data sets, lettering was

Table 3. Geochemical characteristics (total analysis of the bulk material including soil skeleton and find earth) of the selected profiles on transect.

Horizon	Depth cm	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	P_2O_5 (%)	MnO (%)	Cr2O3 (%)
PI/foot slope/25 m (Typic Haplustert/Haplic Vertisol)												
Ap	0–23	59.4a*	13.8	7.0	1.5b*	2.4b*	1.3	1.6	1.0	0.2	0.2	0.1
Bss1	23–65	58.9a	14.0	7.1	1.6b	1.1c	1.0	1.4	1.0	0.1	0.3	0.1
Bss2	65–106	53.2b	13.1	6.5	2.3b	8.2a	1.0	1.4	0.9	0.1	0.2	0.1
C	106–146	52.8b	13.1	6.4	2.5a	8.6a	1.0	1.4	0.8	0.1	0.1	0.0
PII/toe slope/50 m (Vertic Haplustept/Vertic Cambisol)												
Ap	0–15	51.8b*	16.5	9.5a**	2.7	3.1	1.2	3.1a**	1.0	0.3	0.3	0.0
Bw	15–66	54.9a	16.2	8.4b	2.8	2.9	1.3	2.4ab	0.9	0.2	0.2	0.0
C	66–106	53.4a	16.5	8.6b	3.0	3.5	1.3	2.2b	0.9	0.2	0.2	0.0
PIII/low land back slope/132 m (Lithic Ustorthent/Eutric Regosol)												
A	0–19	48.6	17.2	9.1	3.7	3.2	1.3	3.7	0.8	0.4	0.2	0.0
Cr	19–32	—	—	—	—	—	—	—	—	—	—	—
PIV/low land plateau/160 m (Typic Haplustept/Lithic Cambisol)												
A	0–18	48.3b*	17.3	12.9a*	3.2	2.4	1.0	3.8	1.0	0.2	0.2	0.0
Bw	18–57	48.4b	18.4	11.1ab	2.9	2.1	0.8	3.1	1.0	0.2	0.3	0.0
Cr	57–87	51.0a	17.1	10.7b	2.6	2.0	1.1	3.8	1.1	0.2	0.3	0.0
PV/high land back slope/190 m (Lithic Ustorthent/Eutric Regosol)												
A	0–11	46.0	17.1	11.4a*	5.0a*	5.8a*	1.2	3.1a*	0.9	0.4a*	0.2	0.0
Cr	11–65	45.9	18.0	9.3b	2.1b	1.6b	1.0	2.4b	0.9	0.1b	0.2	0.0
PVI/high land plateau/251 m (Vertic Haplustept/Vertic Cambisol)												
A	0–12	52.6ab*	15.3b*	8.8a*	2.2	2.6bc*	1.1	2.6 a*	1.0a*	0.1	0.1	0.0
Bw1	12–41	56.1a	16.0ab	8.6a	1.9	1.8c	1.1	2.4a	1.0a	0.1	0.2	0.0
Bw2	41–84	56.3a	16.5a	8.3a	2.1	1.5c	1.0	2.2a	1.0a	0.1	0.1	0.0
2Ck	84–105	28.5c	8.0b	3.6b	1.7	28.7a	0.5	1.1b	0.4b	0.1	0.1	0.0

*There are significant differences in $p < 0.01$ between values not represented by the same letter in columns.
**There are significant differences in $p < 0.05$ between values not represented by the same letter in columns.

made separately for each property and column. In the PI profile, changes in SiO_2, MgO, and CaO between horizons were statistically significant ($p < 0.01$), while variation in other properties were found to be insignificant. Ap-Bss1 and Bss2-C horizons were determined to be similar to each other for properties whose exchange is significant. The contents of SiO_2, Fe_2O_3 and K_2O showed significant changes in the horizons of the PII profile ($p < 0.01; p < 0.05$). For these properties, the Bw and C horizons are similar to each other, whereas the Ap horizon differs from other horizons. Also, changes in SiO_2 and Fe_2O_3 properties in the PIV profile were found to be statistically significant, while other properties did not lead to significant changes in horizons. In this profile, horizons showed as A and Bw were found to be similar to each other however, C horizon was found to be different from other horizons. Moreover, the contents of SiO_2, Fe_2O_3, Al_2O_3, K_2O, CaO, and TiO_2 of A, Bw1, and Bw2 horizons in the profile coded as PVI were statistically similar, while the 2Ck horizon showed significant changes from other horizons ($p < 0.01$).

XRD diagrams of some genetic horizons and parent materials of the profiles in the study area are given in Figure 3 and also SEM images of primary and clay minerals are given in Figure 4. Since the 2 Ø value in XRD analysis is more than the alkaline feldspar range than clay minerals after 24.5, quartz mineral which is one of the primary minerals was determined in all profile samples on the transect. However, it has been also determined that the prevalence in the amount of quartz increases relatively from the genetic horizons to the parent material.

Besides, common clay minerals and primary minerals in the parent material and genetic horizons of some profiles and relative ratio of these minerals are given in Table 4. As seen from Table 4, while common clay minerals in the study area's soil are smectite, illite, kaolinite, and vermiculite, primary minerals include quartz, zeolite, Ca feldspar, and K feldspar. However, as some of these clay minerals identified are not included in all selected profiles, the relative proportions of them in each profile and horizon may be different in geochemical variation especially in the pedological process. It was determined that the smectite clays were dominant in soils under the influence of pedogenetic process in profiles (PI, PII, PIV, and PV), which have flat-sloping lands and high clay content, and this is followed by the illite group which was 2:1 type but could not swell up. However, while relative ratio of the smectite clay mineral is medium in surface horizons of PI, PII, PIV, and PV profiles, they are getting dominant by increasing depth toward parent material. Kaolinite clay mineral is present at low and very low level in profiles. Vermiculite clay mineral has a limitedly expandable 2:1 lattice crystal structure. The majority of the interchangeable cations in this clay mineral is Mg^{++} ion. These ions are highly hydrated ions and as a result, there are two layers of water molecules between the layers surrounding the Mg^{++} ions. Therefore, they ensure that the inner surfaces are active. Thus, the distance between layers can be approximately 14 nm-A° (Toksoy 1997). This clay type was detected in the parent materials of the profiles on foot and toe slope land positions. In addition, soils contain slightly zeolite (in PII, PIV, and PV) and K-feldspar (PI and PV) as primary minerals. When the soils (Lithic Ustorthent - PI and PV) in slope lands with high slope are examined, while there are moderately abundant illite and smectite clays in the surface horizons, kaolinite clay mineral and quartz are present in low and very low levels. It is also determined that kaolinite and quartz were found to be more in the parent material. Dengiz et al. (2013a) studied some physico-chemical characteristics and weathering rates of soils forming on calcic toposequence and stated that topographic positions have an important effect on morphological, mineralogical, and weathering processes for the formation of different soils under the same parent material and climatic conditions. In that study, geochemical, physico-chemical, clay mineralogy, and weathering rates of Regosol, Cambisol and Vertisol soils located on similar parent material and in different topographic positions were determined and no significant differences between them were reported. While smectite group clays are dominantly found in soil, these are followed by kaolinite and illite.

Weathering indices

Some losses, additions, and transformations occur during the soil formation processes in the profile. Some indices have been developed for the analytical expression of the events occurring within the specified processes. These are mass change indices such as chemical alteration indices (CIA) (Nesbitt and Young 1982), chemical weathering indices (CIW) (Harnois 1988), and basic cations/R_2O_3 indices (Birkeland 1999). By using these indices, chemical weathering rates are tried to be determined comparatively for soils formed on a toposequence in semihumid climatic conditions. The displacement of the elements in the profile during the formation is controlled by different geo-bio-chemical mechanisms. Profile development is affected by soil formation process such as the dissolution or alteration of primary minerals, secondary mineral formation, transportation, ion exchange, in different amounts and ways. Mobility in the redistribution of formed secondary minerals or elements and geochemical changes during the formation are the determining factors (Middelburg et al. 1988). It is also stated that the consumption rates of primary minerals during soil formation, formations of secondary clay, and metal oxides decrease with the age of soil surface (White et al. 2009). Şenol et al. (2014), studied the element losses (Ca, Mg, K, Na, Si, Al, and Fe) and clay mineralogy of soils formed in two different topographies with north and south directions in their study on the effect of weathering rates and clay mineralogy on exposure for soils formed on trachyte/trachyandesite parent material in semiarid conditions. Element losses, enrichment of immobile elements such as titanium (Ti) and mass balance calculations based on their losses and chemical alteration indices (CIA) are determined using weathering indices such as CIW, Bases/R_2O_3 ratio, plagioclase alteration indices (PIA), and product indices (P). According to the indices used in the interpretation of

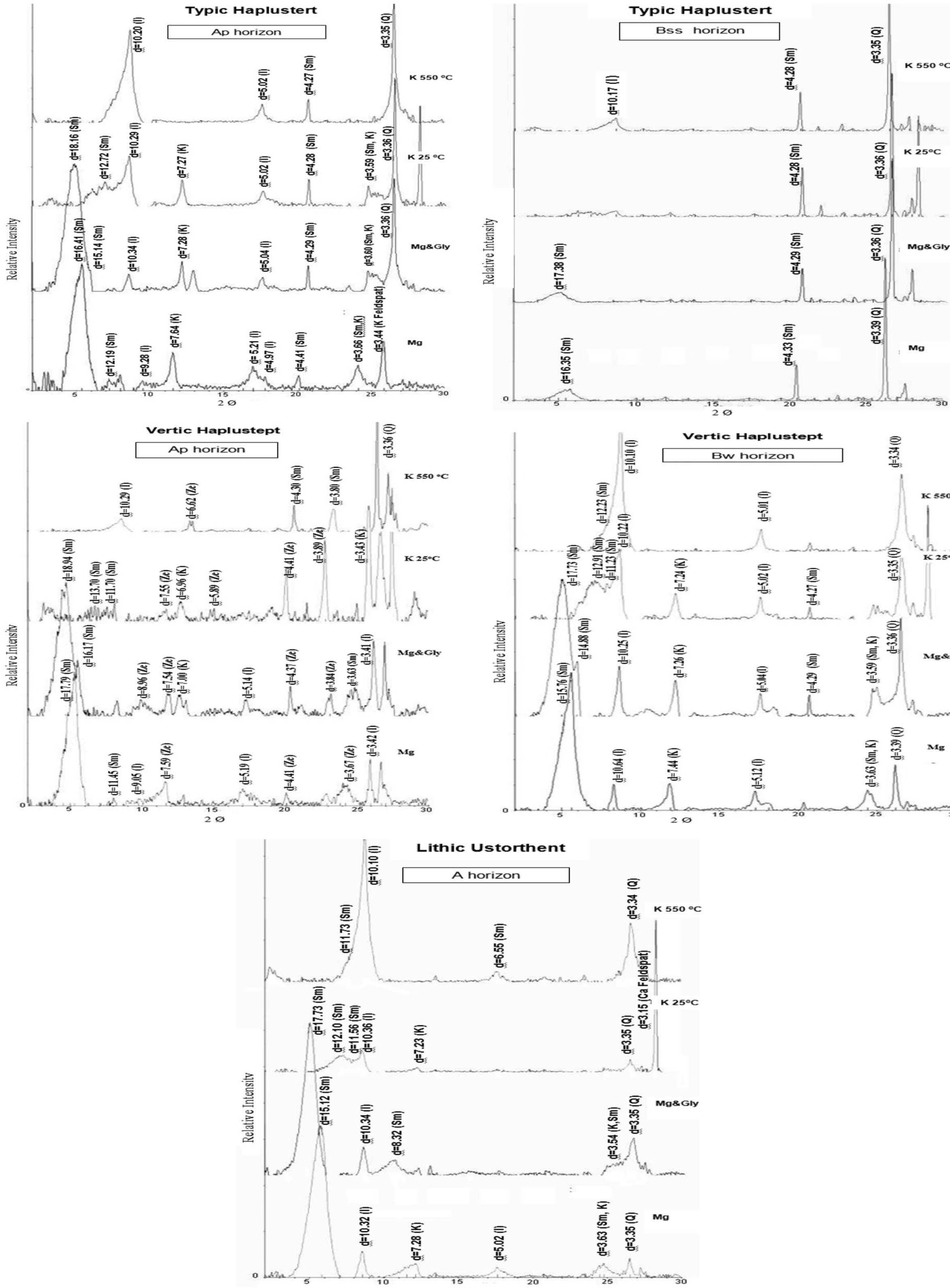

Figure 3. X-ray diffractograms of surface and subsurface horizons for Typic Haplusert, Vertic Haplustept, and Lithic Ustorthent.

weathering medium, the study area profiles were found to be low in accordance with the age of the geological parent material.

Weathering rates produced from the geochemical properties of the profiles on the section in the South-North direction are given in Table 5. CIA value is based on chemical weathering and removal of basic cations such as Ca, Na, and K from minerals and it is a value that reflects the proportion of primary and secondary minerals in the soil. CIA reflects the degree of alteration of feldspars to clays by hydrolytic weathering and it represents the relative clay amount. CIA value is 100 in residual clays such as highly

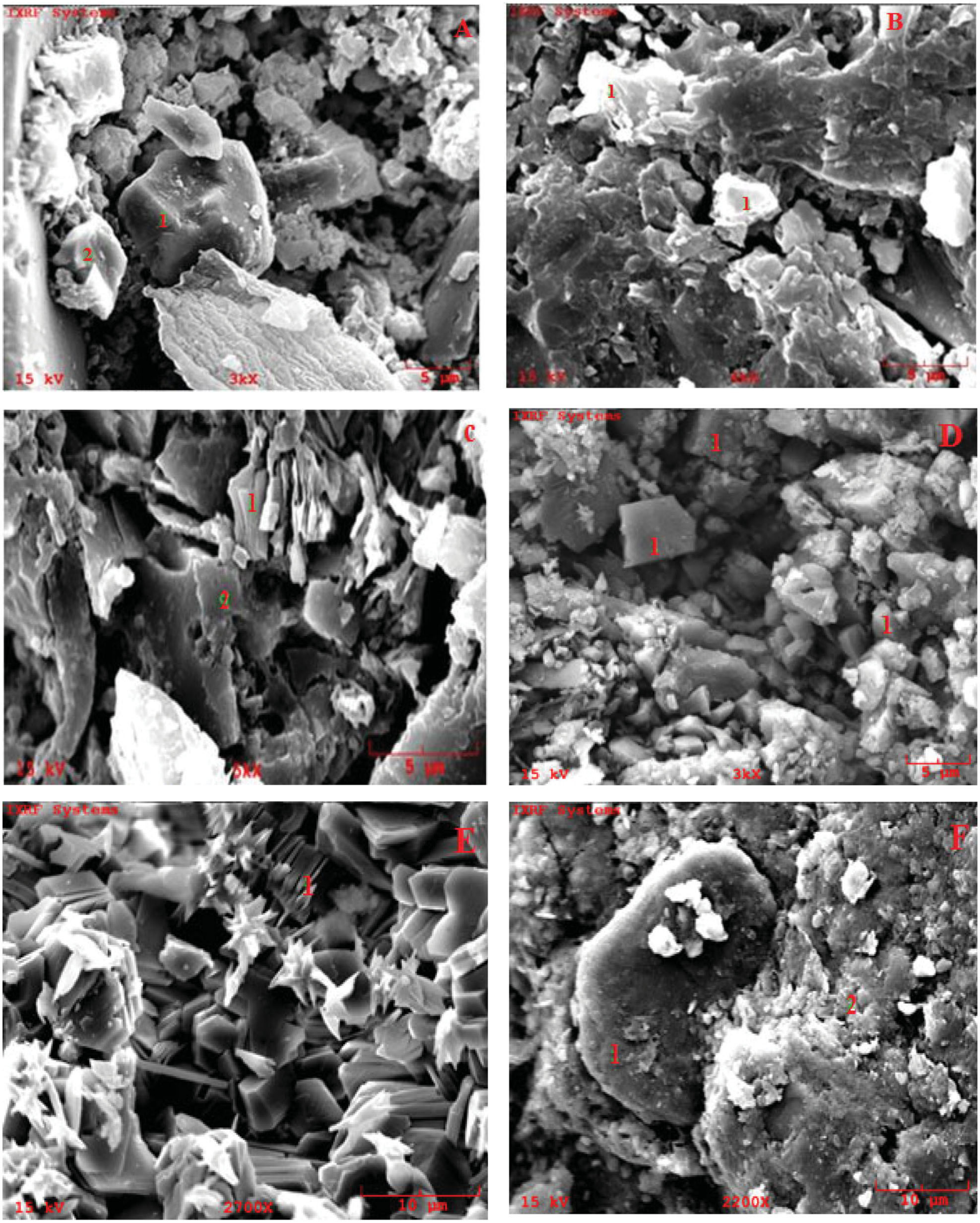

Figure 4. SEM images of clay minerals and primary mineral of soil profiles samples (A: 1: Quartz and 2: Feldspar; B: 1: Smectite; C: 1: Illite and 2: Quartz; D: Zeolite; E: 1: Kaolinite, and F: 1: Vermiculite and 2: illite-Smectite).

weathered and abundant kaolinite or soil or sediments containing minerals such as gibbsite and this value is 50 for unweathered upper rock crust (Fedo et al. 1995), and this value ranges from 70 to 75 on average for rocks such as shale. When CIA values are classified as very low weathered (50–60), low weathered (60–70), moderately weathered (70–80), highly weathered (80–90) and extremely weathered (90–100), CIA weathering rate approaches to 100 depending on the increase in weathering.

The CIA values of the surface horizons of the profiles on the section are close to each other, and they are considered as very low and low weathered level. However, when the

Table 4. The relative ratios of the clay fractions and clay minerals in the horizons of the profiles.

		Clay minerals				Primary minerals			
Horizon	Depth cm	Vermiculite (V)	Illite (I)	Kaolinite (K)	Smectite (Sm)	Quartz (Q)	Zeolite (Ze)	Ca Feldspar	K Feldspar
PI/foot slope/25 m (Typic Haplustert/Haplic Vertisol)									
Ap	0–23	−	+++	++	++++	+	−	−	++
Bss1	23–65	−	++	−	+++	+	−	−	−
Bss2	65–106	−	++	+	+++	+	−	−	−
C	106+	+	+++	++	++++	++	−	−	−
PII/toe slope/50 m (Vertic Haplustept/Vertic Cambisol)									
Ap	0–15	−	+	+	+++	++	++	−	−
Bw	15–66	−	++	+	++++	+	−	−	−
C	66+	++	++	+	+++	+++	−	−	−
PIII/low land back slope/132 m (Lithic Ustorthent/Eutric Regosol)									
A	0–19	−	+++	++	+++	+	−	+	−
Cr	19+	−	−	−	−	−	−	−	−
PIV/low land plateau/160 m (Typic Haplustept/Lithic Cambisol)									
A	0–18	−	++	++	+++	++	+	−	−
Bw	18–57	−	++	++	++++	+	+	−	−
Cr	57+	−	+++	++	++++	++	++	−	−
PV/high land back slope/190 m (Lithic Ustorthent/Eutric Regosol)									
A	0–11	−	++	+	+++	++	−	−	+
Cr	11+	−	+	+++	+++	−	+++	−	−
PVI/high land plateau/251 m (Vertic Haplustept/Vertic Cambisol)									
A	0–12	−	++	−	++	+	−	−	−
Bw1	12–41	−	+++	+	++++	+	−	−	−
Bw2	41–84	−	++	+	++++	+	−	−	−
2Ck	84+	−	++	++	+++	+++	−	−	−

Relative ratio: ++++: Dominant, +++: Medium, ++: Low, +: Very low, −: Non.

Table 5. The weathering indices for the profiles classified according to Soil Survey Staff/IUSS Working Group WRB on the section.

Horizon	Depth (cm)	CIA	CIW	Basic cations/R_2O_3
PI/foot slope/25 m (Typic Haplustert/Haplic Vertisol)				
Ap	0–23	61.9	67.7	0.6
Bss1	23–65	73.8	80.4	0.5
Bss2	65–106	42.3	44.5	1.3
C	106 +	41.3	43.4	1.4
PII/toe slope/50 m *(Vertic Haplustept/Vertic Cambisol)*				
Ap	0–15	60.3	68.8	0.7
Bw	15–66	62.7	69.7	0.7
2Cr	66–106	61.0	66.9	0.8
PIII/low land back slope/132 m (Lithic Ustorthent/Eutric Regosol)				
A	0–19	59.8	69.3	0.9
R	19–32	—	—	—
PIV/low land plateau/160 m (Typic Haplustept/Lithic Cambisol)				
A	0–18	63.5	74.7	0.7
Bw	18–57	69.1	79.0	0.6
Cr	57–87	64.8	76.9	0.6
PV/high land back slope/190 m (Lithic Ustorthent/Eutric Regosol)				
A	0–11	52.1	58.0	1.1
Cr	11–65	71.9	80.2	0.5
PVI/high land plateau/251 m (Vertic Haplustept/Vertic Cambisol)				
A	0–12	63.0	71.0	0.7
Bw1	12–41	68.6	77.0	0.5
Bw2	41–84	71.9	80.1	0.5
2Ck	84–105	12.9	13.1	5.3

CIA: chemical index of alteration; CIW: chemical index of weathering.

weathering conditions depending on the depth increase are examined, the lowest weathering is determined in profile coded as PVI located in the high land plateau and this is followed by the profile PI on the foot slope position. Especially, profile PV situated on high land back slope land was determined to be the soil with the lowest weathering rate, which is formed between parent material and A horizon. Besides, it was found that CIA weathering rates of horizons with high clay content are higher than other layers. As mentioned before, CIW value is 50 in unweathered rock and it closes 100 in heavily weathered mediums and this ratio increasing with weathering. CIW values between profiles show significant differences as the CIA by ranging from 43.4 to 80.4 and the highest and lowest CIW of these soils determined in the profile PI. According to Basic/R_2O_3 values, weathering decreased due to depth increase in all profiles in this line except PI profile and the Base/R_2O_3 values ranged from 0.5 to 1.3. While this rate is generally less than 1 in the soil depth in the profiles located on flat-sloping lands, it was found close to 1 in high land back slope lands.

Microbiological variation

In a study carried out in laboratory conditions by Cockell et al. (2013) on soil weathering, they have shown that in sufficient concentration, the members of *Actinobacteria* in different taxa can increase the separation of the rocks in rocks where carbon, phosphorus, and nitrogen elements are added. Also, some researchers reported that *Micromonospora* members of *Actinobacteria* phylum spread especially in humus-rich soils and plays an important role in the organic matter cycle thanks to their hydrolytic enzymes. They stated that they can break down cellulose, chitin, lignin, and other complex polysaccharides with hydrolytic enzymes (de Menezes et al. 2008; Erikson 1941; Gacto et al. 2000; Wilson 1992).

Four *Actinobacteria* strains (2 *Nonomuraea* and 2 *Streptomyces* strains) and 6 *Actinobacteria* strains (3 *Nonomuraea* and 3 *Streptomyces* strains) were identified in the parent material on the surface horizons of soils on the high land back slope lands and classified as Lithic Ustorthent (PV).

Ten *Actinobacteria* strains (1 *Actinomadura*, 1 *Actinoplymorpha*, 3 *Micromonospora*, 1 *Plantactinospora*, 1 *Rhodococcus* and 3 *Streptomyces* strains) in A horizon, 3

Actinobacteria strains (1 *Nonomuraea* and 2 *Streptomyces* strains) in subcutaneous Bw1 horizon, and 12 *Actinobacteria* strains (1 *Actinomadura*, 8 *Micromonospora* and 3 *Streptomyces* strains) in Bw2 horizon were identified on the high land plateau and classified as Vertic Haplustept (PVI).

Nine *Actinobacteria* strains (1 *Actinomadura*, 3 *Micromonospora* and 5 *Streptomyces* strains) on surface horizons, 8 *Actinobacteria* strains (1 *Actinoplymorpha*, 4 *Micromonospora* and 3 *Streptomyces* strains) in the cambic horizon (Bw) and 4 *Actinobacteria* strains (1 *Actinomadura*, 1 *Micromonospora* and 2 *Streptomyces* strains) in the Cr layer were isolated on the low land plateau of the South-North section and classified as Typic Haplustept.

When morphological characteristics in isolation petri are examined in microbial preliminary studies, many isolates have been observed that can be classified in bacillus, fungi, and actinobacteria groups. When the morphological characteristics of fungi and bacilli from the isolates such as colony morphology and pigment properties are examined, it has been found that many of them are similar and have a low variety. In contrast, when the colonies of actinobacteria are examined according to their morphological characteristics, the findings pointed out that actinobacterium colonies have more diversity compared to fungi (*Absidia*, *Aspergillus*, and *Fusarium*, etc.) and bacilli (*Bacillus*, *Paenibacillus*, etc.) colonies have more diversity. Based on this point, the study focused on determining the diversity of actinobacteria and their molecular identification. According to the research results, 10 different *Actinobacteria* genera (*Actinomadura*, *Actinopolymorpha*, *Nocardia*, *Nonomuraea*, *Micromonospora*, *Plantactinospora*, *Rhodococcus*, *Sacharopolyspora*, *Streptomyces*, *Verrocosispora*) were found and according to 16S rRNA gene region % similarity and nucleotide difference results, isolates *Actinomadura* sp. 14C53, *Rhodococcus* sp. 14C212 and *Plantactinospora* sp. 14C51 from A horizon of Vertic Haplustept (PVI) soils, isolates *Actinomadura* sp. 7C22 and *Nonomuraea* sp. 7N207 from the surface horizon of Vertic Haplustept soil, and isolates *Streptomyces* sp. 9C54 from parent material are among the likely new species.

In the colony counts performed on the isolation plates of the soils sampled from PI, PII, PV and PVI profiles classified as Typic Haplustert, Vertic Haplstept, and Lithic Ustorthent, it was determined that the colony densities changed depending on the amount of organic matter and clay content. Especially, it was found that the microbial density was high in horizons with high organic matter and clay content. Gacto et al. (2000) and Menezes et al. (2008) reported in their study that actinobacteria member organisms play a role in the decomposition of organic material with their hydrolytic enzymes. In addition to that, Dengiz et al (2013b) indicated that various soil textural fractions influence microbial growth and substrate utilization in soils. In their study, the lowest microorganism activity was found in Typic Ustifluvent due to its low organic matter, insufficient nutrient element concentration, low clay, and high sand content. Obtained findings in this study are consistent with this literature information. Since members of *Actinobacteria* are aerobic organisms (Küster 1968), their presence decreases due to the declining of oxygen density as the soil depth increases. It was determined that the density of bacteria in the C horizon of the PI profile, the PII profile in the 2Cr horizon, the PIV profile in the Cr horizon, the PV profile in the Cr horizon, and the PVI profile in the 2Ck horizon were determined to decreasing according to depth and oxygenation concentration.

At the same time, secondary metabolite screening from soil has been intense up to the present day due to the widespread nature of actinobacteria in the soil ecosystem and being highly productive in terms of secondary metabolite production. When it is compared to other bacteria, it showed that there are many genes that encode both new protein genera (especially related to secondary metabolite biosynthesis) and known protein genera (especially regulation, transport, and degradation of extracellular foods) (Bentley et al. 2002). Besides the prevalence of actinobacteria in soils and biological activities in soil formation (effectiveness of exoenzymes for various adhesive molecules and mineralization that they secrete on adherence on organic and inorganic structures occurring during the formation processes of soils of different depths located on different topographic units in which their isolations are carried out especially in the growth development processes of vegetative forms), it has been found that industrially important enzymes produce many commercial bioactive compounds and antitumor agents. In addition to antibiotics, many pesticides, herbicides, anticarcinogenic, antiviral, and antiparasitic metabolites can be isolated from actinobacteria. These metabolites, isolated from actinobacteria, are mainly used in the pharmaceutical industry and agriculture. In recent years, progress has been made in the use of biocatalysts and secondary metabolites isolated from terrestrial actinobacteria. Research and development programs focused on the isolation of new actinobacterial strains from rare studied habitats (Ghosh et al. 2013). Accordingly, as a result of the studies carried out in the samples taken from the soils located on different topographic units in our research area, potentially new species have been found and isolate *Nonomuraea* sp. 160415 from sub-surface Bw1 horizon of Vertic Haplustept (PVI) soils was introduced into the literature as a new species under the name *Nonomuraea basaltis* 160415^{T} (Saricaoglu et al. 2020). With the complementary microbial polyphasic studies (DNA-DNA homology and chemotaxonomic markers-fatty acid profiles, polar lipids, and menaquinone variations) to be done for new potential species (*Actinomadura* sp. 7C22, *Nonomuraea* sp. 7N207 and *Streptomyces* sp. 9C54), it will be the cornerstones of other research projects for bringing microbiological species richness to the literature from our country and defining their primary and secondary metabolite riches.

There are several ways for a direct increase of plant growth by biological nitrogen fixation of different actinobacterium members and to meet the nitrogen need of plants. These can synthesize the siderophore that dissolves the iron from the soil and let it reach the plant, synthesize several different phytohormones that can move to increase the various stages of plant growth, may have mechanisms for dissolving minerals such as phosphorus, potassium, and zinc, which will become more suitable for plant growth, synthesize well-characterized low-molecular mass compounds or enzymes that increase plant growth and development (Kumar et al. 2017). The presence of molecules called siderophores, which are specially synthesized by actinobacteria, suggests that these organisms are also effective in soil formation processes. Siderophore is connected to iron, which is mostly ferric (Fe^{+3}) in soil and basalt material, with a high affinity to dissolve this metal and make it usable for organisms (Fe^{+2}) (Passari et al. 2015). In all genome analysis, it was determined that *Actinomadura* sp. 14C53 and *Nonomuraea basaltis* 160415^T, which are isolated within the context of this study, possess gene regions that produce siderophores.

Soluble P and K concentrations in soil are generally very low because places, where P and K in the soil are at the highest rate, are insoluble rocks, minerals, and other deposits (Bashan et al. 2013). Bacteria offer a biological recovery system that can dissolve insoluble inorganic P and K in the soil and make it usable for plants. Phosphate weathering bacteria are found in mediums containing insoluble phosphate compounds such as tricalcium, iron and aluminum phosphate, hydroxyapatite, bonemeal, rock phosphate, and a single source of phosphate. Such microorganisms release most of the soluble phosphate, which are exceeding their requirements, to the environment (Yadav et al. 2017). It is reported that numerous actinobacterium members including *Arthrobacter*, *Cellulosimicrobium*, *Kocuria*, *Microbacterium*, *Micrococcus*, and *Streptomyces* make phosphate soluble (Verma et al. 2016). In this study, the *Streptomyces* strain was isolated at most. A large number of these strains supports the idea that they contribute to the dissolution of insoluble inorganic P and K of soil.

Conclusion

In this study, physico-chemical, morphological, mineralogical, biological, and geochemical properties of soils formed on basaltic parent material located in different topographic positions (high land plateau, toe slope, and foot slope) in the Engiz Basin were determined. Also, chemical weathering rates of soils formed on a toposequence under semiarid climatic conditions were performed comparatively by adapting the geochemical approach to determine the weathering levels and maturation of these different soils.

The reason for the formation of two different soils in the same area although it is the same parent material, or in other words, the reason why young and mature soils are located together in a local area is the fact that topography or local relief, parent material and time have an important effect on the soil formation process. Besides, factors such as the frequency and type of vegetation on the soil have been found to have an important effect on this situation. Water flows, and therefore soil transport and accumulation appear to be as effective as a formation on site in the maturation or staying young of the soils, especially in soils located on slope lands.

It is determined that selected soils have the most diversity among microorganisms in actinobacterial varieties when compared to fungi and bacillus groups. Especially the fact that microorganism activity is high especially surface soil is due to the use of more organic matter in the upper soil by microorganisms as a source of food and energy. Moreover, it can be said that there is an important relationship between the amount and type of clay and organism activity. It can be explained by clay particles attracting positively charged cations to themselves due to their large surface areas and negative electrical charges and thus bind more plant nutrients and therefore, increase the microorganism activity. It is considered that *Actinomadura* sp. 14C53 and *Nonomuraea basaltis* 160415^T strains, which are actinobacteria isolated from sublayers, have gene regions synthesizing siderophores attacks on a basaltic rock by lowering the pH to obtain the necessary nutrients and increase the dissolution rate when that microorganisms cannot obtain nutrients in biotic conditions in the study carried out by Stranghoener et al. (2018) and thus it is suggested that these organisms contribute to soil formation processes.

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References

Abate N, Kibret K. 2016. Effects of land use, soil depth and topography on soil physicochemical properties along the toposequence at the Wadla Delanta Massif. EP 5(2):57–71.

Alijani Z, Sarmadian F. 2014. The role of topography in changing of soil carbonate content. Indian J Sci Res 6:263–271.

Bashan Y, Kamnev AA, de-Bashan LE. 2013. Tricalcium phosphate is inappropriate as a universal selection factor for isolating and testing phosphate-solubilizing bacteria that enhance plant growth: a proposal for an alternative procedure. Biol Fertil Soils 49(4):465–479.

Bentley SD, Chater KF, Cerdeño-Tárraga A-M, Challis GL, Thomson NR, James KD, Harris DE, Quail MA, Kieser H, Harper D, et al. 2002. Complete genome sequence of the model actinomycete Streptomyces coelicolor A3(2). Nature. 417(6885):141–147. doi:10.1038/417141a.

Berner RA, Lasaga AC, Garrels RM. 1983. The carbonate-silicate geochemical cycle and its effect on atmospheric carbon dioxide over the past 100 million years. Am J Soil Sci 283(7):641–683.

Bin L, Bin W, Mu P, Liu C, Teng HH. 2008. Microbial release of potassium from K-bearing minerals by thermophilic fungus *Aspergillus fumigatus*. Geochim Cosmochim Acta 72(1):87–98.

Birkeland PW. 1999. Soils and Geomorphology. 3rd ed. New York: Oxford University Press.

Blake GR, Hartge KH. 1986. Bulk density. In: Klute, A, editor. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, 2nd ed. Madison, Wisconsin: SSSA Book Series 5.

Bland W, Rolls D. 1995. Weathering: An Introduction to the Scientific Principles. London: Routledge.

Camuffo D. 1995. Physical weathering of stones. Sci Total Environ 167(1–3):1–14.

Bouyoucos GJ. 1951. A recalibration of the hydrometer method for making mechanical analyses of soils. Agron J 43(9):434–438.

Bower CS, Hucker GJ. 1930. Tech. Bull. 228. Geneva, NY: New York State Agricultural Experiment Station.

Brettin T, Davis JJ, Disz T, Edwards RA, Gerdes S, Olsen GJ, Olson R, Overbeek R, Parrello B, Pusch GD, et al. 2015. RASTtk: a modular and extensible implementation of the RAST algorithm for building custom annotation pipelines and annotating batches of genomes. Sci Rep 5:8365.

Cockell CS, Kelly LC, Marteinsson V. 2013. Actinobacteria an ancient phylum active in volcanic rock weathering. Geomicrobiol J 30(8): 706–720.

Cockell CS, Olsson K, Knowles F, Kelly L, Herrera A, Thorsteinsson T, Marteinsson V. 2009. Bacteria in weathered basaltic glass Iceland. Geomicrobiol J 26(7):491–507.

Dahlgren RA, Ugolini FC, Casey WH. 1999. Field weathering rates of Mt. St. Helens Tephra. Geochim Cosmochim Acta 63(5):587–598.

Delvaux B, Herbillon AJ, Vielvoye L. 1989. Characterization of a weathering sequence of soils derived from volcanic ash in Cameroon-taxonomic, mineralogical and agronomic implications. Geoderma 45(3–4):375–388.

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. J Agric Sci 16 (3):205–212.

Dengiz O, Sağlam M, Özaytekin HH, Baskan O. 2013a. Weathering rates and some physico-chemical characteristics of soils developed on a calcic toposequences. Carpath J Earth Environ Sci 8 (2):13–24.

Dengiz O, Şenol H. 2018. Effect of toposequences on geochemical mass balance and clay mineral formation in soils developed on basalt parent material under subhumid climate condition. Indian J Geo Marine Sci 47(9):1809–1820.

Dengiz O, Kizilkaya R, Erkocak A, Durmus M. 2013b. Variables of microbial response in natural soil aggregates for soil characterization in different fluvial land shapes. Geomikrobyology J 30(2):100–107.

Duan L, Hao J, Xie S, Zhou Z, Ye X. 2002. Determining weathering rates of soils in China. Geoderma 110(3–4):205–225.

Edwards KJ, Bach W, McCollom TM, Rogers DR. 2004. Neutrophilic iron-oxidizing bacteria in the ocean: their habitats, diversity, and roles in mineral deposition, rock alteration, and biomass production in the deep-sea. Geomicrobiol J 21(6):393–404.

Erikson D. 1941. Studies on some lake-mud strains of micromonospora. J Bacteriol 41(3):277–300.

Fedo CM, Nesbitt HW, Young GM. 1995. Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols with implications for paleoweathering conditions and provenance. Geol 23(10):921–924.

Gacto M, Vicente Soler J, Cansado J, Villa TG. 2000. Characterization of an extracellular enzyme system produced by *Micromonospora chalcea* with lytic activity on yeast cells. J Appl Microbiol 88(6): 961–967.

Gee GW, Bauder JW. 1986. Particle-size analysis. In: Klute, A, editor. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. 2nd ed. Madison Wisconsin: SSSA Book Series 5, p383–411.

Ghosh PK, Saha P, Mayilraj S, Maiti TK. 2013. Role of IAA metabolizing enzymes on production of IAA in root, nodule of Cajanus cajan and its PGP Rhizobium sp. Biocatal. Agric. Biotechnol. 2(3): 234–239. doi:10.1016/j.bcab.2013.04.002.

Gordon RE, Mihm JM. 1962. The type species of the genus Nocardia. Microbiology 27(1):1–10.

Harnois L. 1988. The CIW Index: a new chemical index of weathering. Sediment Geol 55(3–4):319–322.

Hayakawa M, Nonomura H. 1987. Humic acid-vitamin agar, a new medium for the selective isolation of soil actinomycetes. J Ferment Technol 65(5):501–509.

IUSS Working Group WRB. 2015. World References Base for Soil Resources 2014. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps Update 2015, World Soil Report. Vol. 106. Rome: FAO, p203.

Jenkins DA, Jones RGW. 1980. Trace elements in rock, soil, plant and animal: introduction. In: Davies, BE, editor. Applied Soil Trace Elements. New York: John Wiley and Son Ltd, p1–20.

Jonasson S, Michelsen A, Schmidt IK, Nielsen EV, Callaghan TV. 1996. Microbial biomass C, N and P in two arctic soils and responses to addition of NPK fertilizer and sugar: implications for plant nutrient uptake. Oecologia 106(4):507–515.

Jones KL. 1949. Fresh isolates of actinomycetes in which the presence of sporogenous aerial mycelia is a fluctuating characteristic. J Bacteriol 57(2):141–145.

Kannahi M, Senbagam N. 2014. Studies on siderophore production by microbial isolates obtained from rhizosphere soil and its antibacterial activity. J Chem Pharm Res 6:1142–1145.

Kim O-S, Cho Y-J, Lee K, Yoon S-H, Kim M, Na H, Park S-C, Jeon YS, Lee J-H, Yi H, et al. 2012. Introducing EzTaxon-e: a prokaryotic 16S rRNA gene sequence database with phylotypes that represent uncultured species. Int J Syst Evol Microbiol 62(Pt 3):716–721.

Kumar V, Yadav AN, Verma P, Sangwan P, Saxena A, Kumar K, Singh B. 2017. *β*-Propeller phytases: Diversity, catalytic attributes, current developments and potential biotechnological applications. Int J Biol Macromol 98:595–609.

Küster E. 1968. Taxonomy of soil actinomycetes and related organisms. In: Gray S, Parkinson T, editors. Ecology of Soil Bacteria. Liverpool: Liverpool University Press, p322–336.

Küster E, Williams ST. 1964. Selection of media for isolation of streptomycetes. Nature. 202(4935):928–929.

Le Roux X, Poly F, Currey P, Commeaux C, Hai B, Nicol GW, Prosser JI, Schloter M, Attard E, Klumpp K. 2008. Effects of aboveground grazing on coupling among nitrier activity, abundance and community structure. ISME J 2(2):221–232.

Macagnan D, Romeiro RDS, Pomella AW, deSouza JT. 2008. Production of lytic enzymes and siderophores, and inhibition of germination of basidiospores of Moniliophthora (ex Crinipellis) perniciosa by phylloplane actinomycetes. Biol Control 47(3):309–314.

Menezes RA, Amaral C, Batista-Nascimento L, Santos C, Ferreira RB, Devaux F, Eleutherio ECA, Rodrigues-Pousada C. 2008. Contribution of Yap1 towards *Saccharomyces cerevisiae* adaptation to arsenic-mediated oxidative stress. Biochem J 414(2):301–311.

Middelburg JJ, van der Weijden CH, Woittiez JRW. 1988. Chemical processes affecting the mobility of major, minor and trace elements during weathering of granitic rocks. Chem Geol 68(3–4):253–273.

Nakouti I, Hobbs G. 2013. A new approach to studying ion uptake by actinomycetes. J Basic Microbiol 53(11):913–916.

Navarrete JU, Cappelle IJ, Schnittker K, Borrok DM. 2013. Bioleaching of ilmenite and basalt in the presence of iron-oxidizing and iron-scavenging bacteria. Int J Astrobiol 12(2):123–134.

Nelson DW, Sommer LE. 1982. Total carbon, organic carbon, and organic matter. In: Page, AL, editor. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. Madison, Wisconsin: SSSA Book Series 5, p539–579.

Nesbitt YW, Young GM. 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of Lutites. Nature 299(5885):715–717.

Passari AK, Mishra VK, Saikia R, Gupta VK, Singh BP. 2015. Isolation, abundance and phylogenetic affiliation of endophytic actinomycetes associated with medicinal plants and screening for their *in vitro* antimicrobial biosynthetic potential. Front Microbiol 6:273.

Perez A, Rossano S, Trcera N, Huguenot D, Fourdrin C, Verney-Carron A, van Hullebusch ED, Guyot F. 2016. Bioalteration of synthetic Fe (III)-, Fe (II)-bearing basaltic glasses and Fe-free glass in the presence of the heterotrophic bacteria strain *Pseudomonas aeruginosa*: impact of siderophores. Geochim Cosmochim Acta 188: 147–162.

Pridham TG, Anderson P, Foley C, Lindenfelser LA, Hesseltine CW, Benedict RG. 1957. A selection of media for maintenance and taxonomic study of Streptomycetes. Antibiot Annu 1956–1957:947–953.

Santelli CM, Banerjee N, Bach W, Edwards KJ. 2010. Tapping the subsurface ocean crust biosphere: low biomass and drilling-related contamination calls for improved quality controls. Geomicrobiol J 27(2):158–169.

Saricaoglu S, Saygin H, Topkara AR, Gencbay T, Guven K, Cetin D, Sahin N, Isik K. 2020. Nonomuraea basaltis sp. nov., a siderophore-producing actinobacteria isolated from surface soil of basaltic parent material. Arch Microbiol 202(6):1535–1543.

Şenol H, Özaytekin HH, Akgül M, Alaboz P. 2014. Yarı kurak şartlarda Trakit/Trakitandezit ana materyal üzerinde oluşan toprakların ayrışma oranları ve kil minerolojine bakının etkisi. Tar Bil Der 20(3):288–301.

Singh P, Kumar V, Agrawal S. 2014. Evaluation of phytase producing bacteria for their plant growth promoting activities. Int J Microbiol 4:64–83.

Soil Survey Division Staff. 1993. Soil Survey Manual. Handbook, No: 18. Washington D.C: USDA.

Soil Survey Laboratory. 2004. In: Burt, R editor. Soil Survey Laboratory Methods Manuals, Soil and Water Chemical Extraction Analyses, Soil Survey Investigations Report No. 42. Lincoln, Nebraska: USDA-NRCS Service.

Soil Survey Staff. 1999. Soil Taxonomy: a basic system of soil classification for making and interpreting soil survey. Washington D.C.: USDA Agriculture Handbook No 436; 1999, pp. 869.

Soil Survey Staff. 2014. Keys to Soil Taxonomy. Washington D.C.: United States Department of Agriculture Natural Resources Conservation Service.

Souri B, Watanabe M, Sakagami K. 2006. Contribution of Parker and product indexes to evaluate weathering condition of Yellow Brown Forest soils in Japan. Geoderma 130(3–4):346–355.

Stockmann GJ, Shirokova LS, Pokrovsky OS, Bénézeth P, Bovet N, Gislason SR, Oelkers EH. 2012. Does the presence of heterotrophic bacterium *Pseudomonas reactans* affect basaltic glass dissolution rates? Chem Geol 296:1–18.

Stranghoener M, Schippers A, Dultz S, Behrens H. 2018. Experimental microbial alteration and Fe mobilization from basaltic rocks of the ICDP HSDP2 drill core, Hilo, Hawaii. Front Microbiol 9:1–17.

Tan GYA, Ward AC, Goodfellow M. 2006. Exploration of amycolatopsis diversity in soil using genus-specific primers and novel selective media. Syst Appl Microbiol 29(7):557–569.

Tang Y, Zhang X, Zhou J, Yu S, Yang P, Wan J. 2010. The mechanism of underground leakage of soil in karst rocky desertification area-A case in Chenqi small watershed, Puding, Guizhou Province. Carsologica Sinica 29:121–127.

Taylor TN, Taylor EL. 2000. The Rhynie chert ecosystem: a model for understanding fungal interactions. In: Bacon, CW, White, JF, editors. Microbial Endophytes. New York: Marcel Dekker, p31–47.

Toksoy F. 1997. Vermikülit: Mineraloji, Jeolojik Oluşum, Endüstriyel Kullanı m ve Türkiye'deki Durumu. 2 Endüstriyel Hammaddeler Sempozyumu, 16-17 Ekim 1997, İzmir-Türkiye, pp. 123–138. (in Turkish)

TSMS. 2020. Turkish State Meteorological Service. Reference Crop Evapotranspiration Maps. Accessed April 12, 2020. Available at https://mgm.gov.tr/tarim/referans-toplam-buharlasma.aspx.

Tunçay T, Dengiz O. 2016. Chemical weathering rates and geochemical-mineralogical characteristics of soils developed on heterogeneous parent material and toposequence. Carpath J Earth Environ Sci 11:583–598.

Tunçay T, Dengiz O, İmamoğlu A. 2020. Influence of toposequence on physical and mineralogical properties of soils developed on basaltic parent material under sub-humid terrestrial ecosystem. J Agric Sci 26:104–116.

Verma P, Yadav AN, Khannam KS, Mishra S, Kumar S, Saxena Ak, Suman A. 2016. Appraisal of diversity and functional attributes of thermotolerant wheat associated bacteria from the peninsular zone of India. Saudi J Biol Sci 26:1882–1895.

Vickers JC, Williams ST, Ross GW. 1984. A taxonomic approach to selective isolation of streptomycetes from soil. In: Ortiz-Ortiz, L, Bojalil, LF, Yakoleff, V, editors. Biological, Biochemical and Biomedical Aspects of Actinomycetes. London: Academic Press, p553–561.

Waksman SA. 1927. Principles of Soil Microbiology. Baltimore, MD: Williams & Wilkins.

Weber T, Blin K, Duddela S, Krug D, Kim HU, Bruccoleri R, Lee SY, Fischbach MA, Müller R, Wohlleben W, et al. 2015. antiSMASH 3.0—a comprehensive resource for the genome mining of biosynthetic gene clusters. Nucleic Acids Res. 43(W1):W237–243.

Weyland H. 1969. Actinomycetes in North Sea and Atlantic ocean sediments. Nature. 223(5208):858.

White AF, Schulz MS, Stonestrom DA, Vivit DV, Fitzpatrick J, Bullen TD, Maher K, Blum AE. 2009. Chemical weathering of a marine terrace chronosequence, Santa Cruz, California. Part II: solute profiles, gradients and the comparisons of contemporary and long-term weathering rates. Geochim Cosmochim Acta 73(10):2769–2803.

Whittig LD, Allardice WR. 1986. X-ray diffraction techniques. In: Klute, A, editor. Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. 2nd ed. Madison, Wisconsin: ASA Publication 9, p55–86.

Wilson DB. 1992. Biochemistry and genetics of actinomycete cellulases. Crit Rev Biotechnol. 12(1–2):45–63.

Wu L, Jacobson AD, Chen HC, Hausner M. 2007. Characterization of elemental release during microbe–basalt interactions at T: 28 C. Geochim Cosmochim Acta 71(9):2224–2239.

Yadav AN, Verma P, Kour D, Rana KL, Kumar V, Singh B, Dhaliwal HS. 2017. Plant microbiomes and its beneficial multifunctional plant growth promoting attributes. IJESNR 3(1):1–8.