



Genesis, mineralogy, and geochemistry of soil profiles developed on volcanic materials under semi-arid conditions from Central Anatolia-Turkey

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ABSTRACT

Pedogenesis of volcanic soils has been studied broadly in humid regions, but very little data are present regarding these soils in arid and semi-arid regions of Turkey. This research aimed to assess the pedological processes and investigate the physical, chemical, and mineralogical characteristics of soil profiles developed from volcanic parent material. The studied soils were not classified as Andisol because they lack andic properties. The results showed that sand and coarse silt fractions exceeded 30%. The bulk density was higher than 0.90 gcm⁻³ in all profiles. In general, phosphate retention was low, higher than 25% in profiles but lower than 85% in all profiles. The Al + $\frac{1}{2}$ Fe_d percentages were lower than 2% in all profiles. Selective extraction (Na–Pyrophosphate, Ammonium Oxalate, Na–Dithionite) indicated that soils lack noncrystalline minerals, such as allophane, imogolite, and iron humus complexes. The only noncrystalline minerals in high quantities are Al-humus complexes and small amounts of ferrihydrite. X-ray diffraction indicated that smectite, kaolinite and illite were dominant minerals in the clay fraction. Among the studied profiles, profiles 1 and profile 4 are classified as vitrandic Haploxerept, profile 2 as vitrandic haploxerolls, and profile 3 as vitrandic Xerorthent. The results indicated that the dominant soil-forming processes include the following: 1. desilication and the eluviations of base cations and Al from the solum; and 2. transformation of iron and aluminum from the sand and silt-size fractions into secondary clay and crystalline Fe minerals. The major factors determining soil genesis on Mt. Karacadağ appear to be climate and topography affected by the leaching regime and weathering rates.

Keywords: Karacadağ; Andisols; Weathering; Elemental losses; Allophane; Andic soil properties.

Génesis, mineralogía y geoquímica de perfiles de suelo desarrollados con material volcánico bajo condiciones semiáridas en Anatolia Central, Turquía

RESUMEN

La pedogénesis de los suelos volcánicos se ha estudiado ampliamente en regiones húmedas, sin embargo hay muy poca información sobre estos suelos en las regiones áridas y semiáridas de Turquía. Este trabajo se enfoca en evaluar los procesos pedológicos y en investigar las características físicas, químicas y mineralógicas de perfiles de suelo desarrollados con materiales volcánicos. Los suelos estudiados no fueron clasificados como Andisoles porque carecen de propiedades andicas. Los resultados muestran que las arenas y las fracciones de arena granulada exceden el 30 %. La densidad del volumen fue mayor a 0.90 gcm⁻³ en todos los perfiles. En general la retención de fosfato fue baja, mayor a 25 % y menor a 85 % en todos los perfiles. Los porcentajes Al + $\frac{1}{2}$ Fe_d fueron menores al 2 % en todos los perfiles. La extracción selectiva (pirofosfato de sodio, oxalato de amonio, ditionito de sodio) indica que los suelos carecen de minerales no cristalinos como la alfofanita, imogolita y compuestos húmicos de hierro. Los únicos minerales no cristalinos en altas cantidades son los compuestos húmicos de aluminio y pequeñas cantidades de ferrihidrita. La difracción de rayos X indican que la esmectita, caolinita e illita son los minerales dominantes en la fracción arcillosa. De los perfiles estudiados, el 1 y el 4 se clasificaron como vitrandic haploxerepts, mientras que el perfil 2 como vitrandic haploxerolls y el perfil 3 como vitrandic xerorthents. Los resultados indicaron que los procesos de formación del suelo incluyen las siguientes características: 1. Desilicación e iluviación de cationes base y de aluminio desde el solum; 2. Transformación del hierro y el aluminio de las arenas y de las fracciones arenosas en arcillas secundarias y en minerales ferrosos cristalinos. Los mayores factores determinantes en la génesis del suelo en las montañas turcas de Karacadağ son el clima y la topografía, afectadas por el régimen de lixiviación y la tasa de meteorización.

Palabras clave: montañas turcas de Karacadağ; Andisoles; Meteorización; Pérdida de elementos; alfofanita; Propiedades andicas del suelo.

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1. Introduction

The Andisols (Keys to Soil Taxonomy, 2014) have a unique combination of physical and chemical properties linked to the abundance of short-ordered minerals and/or insoluble Al-humus complexes. After tephra deposition, soil formation begins, and the tephra's elemental and mineralogical composition changes; consequently, volcanic ash soils or Andisols with unique properties are formed (Nanzyo, 2002). The formation of poorly crystallized minerals and the accumulation of organic matter occur preferentially in volcanic ash soils (Shoji et al., 1996). While soils formed from volcanic materials in different climatic regions of the world are different, they share unique properties, particularly during the early and intermediate stages of development. Typically, the weathering of volcanic deposits results in the formation of Andisols in both temperate and tropical environments with sufficient moisture (Shoji et al., 1993). Andisols form rapidly in humid climates and change into other soil orders with age and degree of weathering (Ugolini and Dahlgren, 2003), e.g., very old and highly weathered volcanic ash soils may change from Andisols into Ultisols or Oxisols. Climatic conditions are an important factor for mineral weathering and formation because the climate determines the weathering product of volcanic materials in addition to the parent material. Most of the studies related volcanic soils have occurred where precipitation is >1000 mm and where andic characteristics have developed in-situ and cannot be disputed (Özcan and Özyaytekin, 2011). In comparison to the Andisols from humid regions, minimal information is available concerning the volcanic soils of semiarid climates in Italy (Egli et al., 2008), Greece (Moustakas and Georgoulas, 2005), and Turkey (Ozyaytekin and Ozcan, 2013; Senol et al., 2017). The fact that noncrystalline mineral formation results from over-saturation of the soil solution with Si, Al, and Fe, concentrations, makes it easy to understand the influence of climate on volcanic soil. Mediterranean environments, such as Turkey, may appear too hot and dry for andosolization, despite the widespread occurrence of volcanic areas. The Central Anatolia has arid and semi arid climatic conditions. The decomposition products of volcanic material formed in semi-arid climatic conditions such as Central Anatolia are different from those formed in rainy areas, and Andisol formation has not been fully demonstrated in these environments. Scarce information is currently available regarding Andisol properties in Turkey. It is the purpose of the present paper to describe the soil formation processes of soils developed on volcanic materials in semiarid region of Anatolia. Therefore, this research was conducted to evaluate the physicochemical properties, weathering processes, and pedogenetic products of soils developed from an andesite on Mount Karacadağ in Konya, a semiarid region, and to classify the soils using one of the current international classification system. We discuss the extent to which these soils meet the requirements of soils classified as Andisols, in Soil Taxonomy (Soil Survey Staff, 2014).

2. Materials and Methods

Site description

The study was conducted with soils developed from a parent material derived from volcanic activity during the Pliocene in Karacadağ, which is located in eastern Konya. Karacadağ is situated approximately 10 kilometers east of Karapınar, located between a 37°40'-37°50' northern latitude and 33°40'-33°54' eastern longitude, which extend to the northwest and southeast, respectively, and it, covers an area of approximately 200 square kilometers. Karacadağ consists of five separate volcanic series, the first three of which are Pliocene and the last two of which are Quaternary eruptions, each containing numerous lava and pyroclastic products. The mean annual precipitation around Karapınar is 379.4 millimeters, and the annual evaporation rate is 1226.4 millimeters. The mean annual temperature is 11.5 °C, and the mean soil temperature at a depth of 50 cm is 12.5 °C. According to the climate data, the soil moisture and temperature regimes are xeric and mesic, respectively (Soil Survey Staff, 2014). The products of Karacadağ volcanism, are composed of successive volcanic rocks, first as andesitic lava, next as andesitic agglomerate-tuff, then as andesitic lava and andesitic-basaltic lava in the Quaternary, and later as basaltic lava (Ayhan and Sevin, 1986). Sanidine and olivine-bearing basalts with ages between 45,000 and 336,000 years are exposed

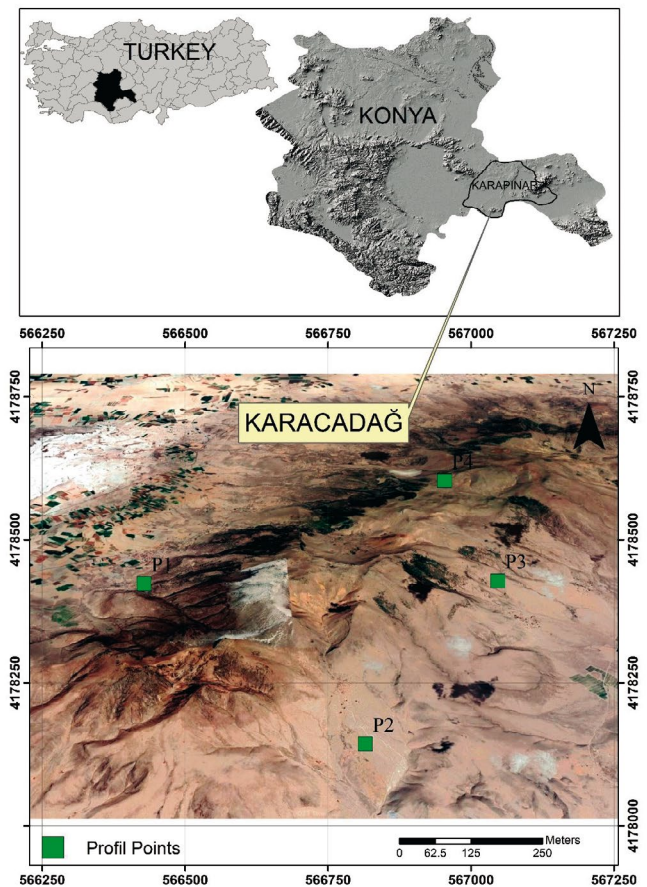


Figure 1. Location of the study area

Sampling and analysis

For this study, 4 representative soil profiles were chosen, and disturbed and undisturbed (bulk core) soil samples were obtained from the horizons after their macro morphological identification was completed. The soil pH was measured in a both soil-water (w/v) suspension and 0.01 N KCl with a soil/ solution ratio of 1/2.5. Measurements of (NaF) pH 1 M (1:50) after 2 min of equilibration were taken, as prescribed by the USDA (Soil Survey Staff 2009). The electrical conductivity (EC) was potentiometrically determined in a 1/2.5 soil-water suspension (Soil Survey Staff, 2009). The soil texture was determined using a hydrometer method (Bouyoucos, 1951) after the removal of organic matter using H₂O₂ and after the soil was stirred into a sodium hexametaphosphate solution. The bulk density was determined from the dry weight of 100 cm³ undisturbed core samples (Soil Survey Staff, 2009). Phosphate retention was determined based on the methods of Blakemore et al. (1987). The total soil organic carbon (C_{org}) was determined using the Walkley-Black wet digestion method (Soil Survey Staff, 2009). The exchangeable bases were extracted with a neutral 1 M NH₄-acetate, and the bases were determined using atomic absorption spectroscopy (Soil Survey Staff, 2009). The cation exchange capacity (CEC) was determined using ammonium acetate (1 N, at pH 7), and the quantity was determined using a flame photometer (Soil Survey Staff, 2009). The water retention capacity was measured in the disturbed soil samples at -1500 kPa and -33 kPa and using suction plate and pressure plate methods (Peters, 1965). The carbonate in the soil was measured with a Scheibler calcimeter (Soil Survey Staff, 2009). The percent base saturation was determined by dividing the sum of the K, Mg, Ca, and Na in mEq 100 g⁻¹ soil by the CEC. A technique modified from Mizota and van Reeuwijk (1989) was used to dissolve Fe, Al, and Si selectively. To achieve this, extraction solutions of dark ammonium oxalate, dithionite-citrate bicarbonate (DCB), and sodium

pyrophosphate-extractable Si, Al, and Fe were obtained. Atomic absorption spectrophotometry (AAS) was used for all procedures to determine the concentrations of Si, Al, and Fe. (Soil Survey Staff, 2009). The subscripts o, d, and p stood for the corresponding methods' cations. The major, minor and rare earth elements of the soil and rock samples was determined by acid digestion in microwave oven in HF/HNO₃ 1:5 solution at 600 W for 24 min (Chao and Sanzalone, 1992), the contents were measured using inductively coupled plasma (ICP). All of these procedures were replicated 3 times for each soil sample, and the means were reported. The whole soil and clay mineralogy were achieved using X-ray diffraction (XRD) on powdered samples as randomly oriented powder mounts with a Shimadzu XRD-6000 with a Cu anticathode and K filter (40 kV, 35 mA). The whole soil samples were powdered to 40 µm using a sintered Al oxides mortar grinder. An aliquot was separated and mounted as unoriented powder using the back-side method (Brindley and Brown, 1980).

The powder was submitted to XRD between 2° and 40° 2θ, and the data were analyzed in a semi-quantitative manner. The oriented specimens of the clay-size fraction were realized using a "glass-slide" method and were analyzed using X-ray diffraction with Cu Kα radiation from 2° to 15° 2θ, with steps of 0.02° 2θ at 2s step⁻¹. The clay fraction (<2 µm) was obtained from the soil after the destruction of organic matter with dilution and Na-acetate-buffered H₂O₂ (pH 5), followed by dispersion with calgon and sedimentation in water. The following treatments were performed: Mg saturation, ethylene glycol solvation (EG), and K saturation, followed by heating for 2 h at 550 °C. The IR spectra were recorded over a range of 4000 to 400 cm⁻¹ with pellets made from 1 mg of sample and 250 mg of KBr, which were previously heated to 150 °C (White and Roth, 1986). The volcanic glass contents from the 0.02-2.00 mm fraction were also observed using a glass slide with a polarizing microscope.

Table 1. Selected morphological characteristics of profiles

Profile	Horizon	Depth (cm)	Color (dry)	Color (moist)	Structure ^a	Field texture ^b	Roots ^c	Boundary	Parent material	Elevation(m) Physiography
1	A1	0-27	10YR5/4	10YR4/4	gr	SC	3-k	gradual, smooth	Andesite-Basalt	1245 Moderately steep
	A2	27-49	10YR5/4	10YR4/4	gr	SC	2-o	gradual, smooth		
	Bw1	49-87	10YR4/4	10YR3/3	ab	SC	2-i	gradual, smooth		
	Bw2	87-115	10YR4/3	10YR4/2	ab	SC	1	gradual, smooth		
	C	115-133	10YR8/2	10YR8/3	mas	C	1	clear, wavy		
	Cr	+133	10YR8/2	10YR8/3	mas	C	1	-		
2	A1	0-31	7,5YR4/3	10YR3/2	gr	SC	3-k	clear - smooth	Andesite	1156 Moderately steep
	A2	31-43	7,5YR4/3	10YR4/3	gr	SC	2-o	abrupt-smooth		
	C	43-79	10YR8/2	7,5YR8/2	ma	SL	1	gradual - smooth		
	Cr	+79	10YR8/1	7,5YR8/2	ma	SCL	1	-		
3	A1	0-21	10YR6/2	10YR3/3	gr	SCL	3-o	gradual - smooth	Basalt	1306 Steep slopes
	A2	21-33	10YR4/3	10YR3/4	gr	SCL	2-o	clear - smooth		
	Cr	33-69	10YR8/3	7,5YR8/2	ma	SL	1	gradual -irregular		
	R	+69	-	-	-	-	-	-		
4	A1	0-16	10YR6/2	10YR3/4	gr	SC	3-k	clear - smooth	Basalt	1371 Moderately steep
	A2	16-50	10YR6/2	10YR3/4	gr	SC	3-k	abrupt - smooth		
	Bw1	50-79	10YR6/2	10YR4/3	ab	C	2-i	clear - smooth		
	Bw2	79-160	10YR6/2	10YR3/4	ab	C	1	abrupt - smooth		
	C	160-183	10YR7/2	10YR6/4	ma	C	1	abrupt -irregular		
	Cr	183-200	10YR8/2	10YR7/4	ma	C	1	-		

^aStructure: mas, massive; gr, granular; ab, angular blocky; p, prismatic ^bField texture: SC: sandy clay, C: clay,; SL: sandy loam; SCL: sandy clay loam ^cRoots: 1, none; 2, few; 3, moderate; 4, common; i, fine (<2 mm); o, medium (2-5 mm); k, coarse (>5 mm).

3. Results

Morphological properties

The profiles developed on an andesitic-basalt parent material on steep or moderate hill topography in a xeric moisture and mesic temperature regime. In profiles 2 and 3, there are no pedogenetic horizons other than A horizon, whereas B horizon was identified in profiles 1 and 4 in addition to an A horizon. The fact that the horizon differences aren't high and that the parent material exhibits low weathering rates indicates that soil evolution is in the preliminary stages. Of the profiles, profile 1 and profile 4 were fine textured, and profile 2 and profile 3 were coarse textured. Structural development was poor, or no development was present in all of the analyzed profiles, except in the surface horizons, whereas a granular structure was identified on the surface. An angular blocky structure was identified in the cambic horizons, and a massive structure was identified in the C horizon. The hue values in the profiles in Karacadağ range from 7.5 YR to 10 YR and generally have high values when it is dry (Table 1). Since the area where the profiles are opened is pasture and covered with oak or pine trees, the organic matter accumulation rate on the surface is higher than the subsurface layers, causing the surface horizons to show lower values and chroma. These differences resulted from differences in the organic matter, roots and levels of biological activity. A strong reaction with HCl was identified in all of the profile horizons. The presence of weak carbonate micelles in the profile also supports this situation.

Physical and chemical properties

The physical and chemical properties of the studied profiles and the values of andic properties are given in Tables 2, and 3. The pH in the soil water was above 7 due to the content of carbonates, whereas the pH in KCl in all of the horizons was lower than that in pure water. The pH (H₂O) was alkaline in all of the profiles and varied between 7.95 and 8.54, whereas the pH in KCl ranged from 7.33 to 7.98. The Δ pH (pH KCl – pH H₂O) was negative (-) in all horizons, and this indicated a negative charge in all horizons. This signals the presence of a net negative charge in all of the horizons, whereas the pH_{Naf} differed between 10.26 and 10.83. The organic matter content decreased rapidly with depth in all of the profiles and all soils followed the general trend of having the highest organic matter content on the surface. The organic matter content increased to proportionally high values, particularly in the surface horizon of profiles 2 and 4. The organic matter content was low in the other horizons. The organic matter content in the profiles ranged from 0.37% to 4.44%. The lowest values were observed in the Cr horizons. High rates of lime were detected in the profiles, and the lime content ranged from 3.6 % to 77.0 %. Lime content tended to increase with depth except profile 1, which initially shows a reduction. Although the soils in the study area are of volcanic origin, high carbonate contents were detected in the profiles opened. It is known that there are four sources of carbonates found in basaltic parent material. These; 1. As basaltic lavas flow, they absorb parts of the carbonate material underneath, 2. Ca minerals in the basalt form CaCO₃ in suitable environments, 3. Crystallization of lime-rich hydrothermal waters in the pores after the flow of basaltic lavas, 4. recalcification by wind materials containing carbonate (Kapur, 1980; Gürel, 1992; Karaman et al., 1995). Primary mineral examination in the research region revealed the presence of Ca minerals in the soils, including augite, plagioclase, and diopside. The high carbonate content in this location can be explained by the formation of CaCO₃ by the minerals in question. The electrical conductivity of the soils ranged from 118 μ mhos cm⁻¹ to 286 μ mhos cm⁻¹.

All of the profiles were salt-free. The CEC was distributed between 6.60 and 34.99 (cmolc kg⁻¹). The CEC value varied with the amount of clay and organic matter in the horizons and decreased with depth, whereas an increase was observed in the cambic horizons. The exchangeable cations in the soils were identified to be Ca>Mg>K>Na. Ca+Mg varied between 6.25 and

32.37 (cmolc kg⁻¹), the Na ranged between 0.04 and 2.51 (cmolc kg⁻¹) and the K ranged between 0.15 and 3.54 (cmolc kg⁻¹). The number of exchangeable cations generally decreased with the soil depth. The base saturation was identified as 100 %. This indicated that active forms of Al and Fe do not accumulate in the soil. The phosphorous fixation capacities of the soils ranged from 32.45 % to 79.76 %, and it was <85% in all horizons but higher than 25% all profiles. The phosphate retention values of the studied soils fully meet the requirement 3b of andic soil properties according to soil taxonomy. The bulk density changed between 1.32 and 1.66 g cm⁻³. The bulk density values were generally high because of the high sand content of the soils. The textures of the soils are clayey and clay-loamy in profiles 1 and 4, and in profiles 2 and 3, they are sandy-clayey loam and sandy clay. The clay content of the soils ranged between 18.1% and 58.1 %, the sand content ranged between 27.9 % and 66.9 %, and the silt content ranged between 12.0% and 23.5 %. The amount of water retention at -1500 kPa was comparatively low and ranged between 13 % and 22 %. This value was lower than the expected value when compared with Andisols of elsewhere (%35-45). The high sand and the low organic matter content of the soils influenced distribution. Similarly, low rates of water retention were also observed at -33 kPa. The water retention at this pressure was between 18.6 and 35.2. The results of the analyses carried out with selective solutions are given in Table 3.

The Si_i content in some of the profiles was lower than 0.2 % and varied from 0.058% to 0.247 %. The Si_o did not exhibit an obvious trend in the profile distributions in the surface and sub-surface horizons. The Al_o content ranged from 0.014 % to 0.043 %. Fe_o ranged between 0.008% and 1.298%. The Fe_p and Al_p values were notably low in the studied profiles and ranged from 0.0013 to 0.0599% and from 0.017 to 0.050%, respectively (Table 3). Such low values were a result of the low organic matter content; in contrast to volcanic areas, they formed in wet regions of the world. Dithionite-citrate-bicarbonate unlike other solutions, it has a stronger effect on compounds that are in crystalline form. The Fe_d in the profiles ranged from 0.038 % to 0.789 %, whereas the Al_d ranged from 0.007 to 0.093. The Fe_d tended to decrease with depth, whereas the Al_d tended to increase from the surface to sub-surface but decreased again after that. The distribution of major and minor elements is given in Table 4.

The SiO₂ content ranged from 7.7% to 50.04%. The Al₂O₃ content varied between 2.21 % and 14.90% and tended to decrease with depth. The amount of Al in the soil is directly related to the distribution of clay, and the amount of Al₂O₃ increases in mature soils. The amount of Al₂O₃ in the studied soils was close to that of the parent material in the solution due to the low rate of weathering. The Si and Al values differed in the profiles, depending on the sand and clay content of the profiles. The highest value of Fe₂O₃ was observed on the surface horizons, and it reached 8.03%. The amount of Fe₂O₃ ranged from 1.10% to 8.0 % (Table 4). The percentage of CaO exhibited higher levels in the parent material compared with the upper horizons. As the CaCO₃ mineral content in the soil increases, the relative amount of silicate minerals decreases and accordingly the amount of SiO₂ decreases. The percentage of CaO exhibited a distribution between 8.02 and 46.45, whereas the MgO values ranged from 1.57 to 5.82 %. The generally high values of MgO resulted from the presence of significant amounts of minerals with ferro magnesium. High amphibole and biotite peaks have also been observed in primary mineral analyses. The percentages of K₂O and Na₂O were between 0.23% and 3.09% and 0.15% and 3.27%, respectively. This is closely related to the distribution of feldspars that are present in andesite and basalt. Titanium is a mineral resistant to and used for identification of chemical change. The TiO₂ content in the soils ranged between 0.11 and 0.90%, the MnO₂ ranged between 0.01% and 0.14 %, and the P₂O₅ ranged between 0.03% and 0.53%. A regular trend was observed between the horizons in the distribution of other minor elements.

Table 2. Some chemical and physical properties of studied profiles

Profile	Horizon	Depth (cm)	pH _(H₂O) (1/2.5)	pH _(KCL) (1/2.5)	ΔpH KCl-H ₂ O	pH _(NaF) (1/50)	EC (μS/cm)	Organic Matter (%)	CaCO ₃ (%)		
1	A1	0-27	7.95	7.38	-0.57	10.63	127	2.01	36.7		
	A2	27-49	7.97	7.46	-0.51	10.63	122	1.30	29.9		
	Bw1	49-87	8.06	7.49	-0.57	10.66	118	1.20	27.6		
	Bw2	87-115	8.26	7.55	-0.71	10.61	220	1.05	27.8		
	C	115-133	8.44	7.98	-0.46	10.78	165	0.86	61.5		
	Cr	+133	8.53	7.69	-0.83	10.83	222	0.37	63.8		
2	A1	0-31	8.02	7.56	-0.46	10.78	223	4.44	22.3		
	A2	31-43	8.14	7.57	-0.57	10.80	258	2.38	31.0		
	C	43-79	8.48	7.88	-0.60	10.76	180	1.00	77.0		
	Cr	+79	8.54	7.84	-0.70	10.74	189	0.77	75.0		
3	A1	0-21	8.29	7.38	-0.91	10.26	203	2.33	3.6		
	A2	21-33	8.10	7.35	-0.75	10.34	209	1.41	4.5		
	Cr	33-69	8.20	7.54	-0.66	10.74	248	1.33	35.7		
	R	+69	-	-	-	-	-	-	-		
4	A1	0-16	8.14	7.38	-0.76	10.44	246	3.32	11.6		
	A2	16-50	8.24	7.39	-0.85	10.44	193	2.02	12.9		
	Bw1	50-79	8.21	7.33	-0.88	10.53	197	1.59	13.8		
	Bw2	79-160	8.28	7.45	-0.84	10.61	207	1.15	20.5		
	C	160-183	8.41	7.56	-0.85	10.72	242	0.79	37.2		
	Cr	183-200	8.32	7.61	-0.71	10.82	286	0.77	59.5		
Profile	Horizon	Depth (cm)	Particle size distribution (%)			C.E.C. (cmolc kg ⁻¹)	Base Sat. (%)	Exch. cations (cmolc kg ⁻¹)			
			Sand	Clay	Silt			Ca+Mg	Mg	Na	K
1	A1	0-27	41.9	42.6	15.5	22.67	100	20.97	2.37	0.04	1.66
	A2	27-49	42.9	44.1	13.0	22.60	100	21.06	2.20	0.11	1.43
	Bw1	49-87	42.9	42.1	15.0	23.08	100	21.53	2.32	0.16	1.39
	Bw2	87-1115	46.9	40.1	13.0	25.01	100	23.61	2.67	0.26	1.14
	C	115-133	34.9	53.1	12.0	14.97	100	14.10	2.42	0.29	0.58
	Cr	+133	27.9	58.1	14.0	13.77	100	13.13	2.35	0.23	0.41
2	A1	0-31	52.9	25.6	21.5	22.05	100	20.62	1.91	0.09	1.34
	A2	31-43	51.9	28.1	20.0	21.00	100	20.02	1.87	0.14	0.84
	C	43-79	66.9	18.1	15.0	6.60	100	6.25	1.41	0.21	0.15
	Cr	+79	59.9	24.6	15.5	8.51	100	8.10	0.30	0.20	0.20
3	A1	0-21	53.9	26.1	20.0	24.05	100	21.89	2.34	0.10	2.06
	A2	21-33	47.9	36.1	16.0	27.07	100	24.27	2.88	0.16	2.64
	Cr	33-69	46.9	36.1	17.0	23.80	100	22.00	2.63	0.50	1.30
	R	+69	-	-	-	-	-	-	-	-	-
4	A1	0-16	41.9	34.6	23.5	28.00	100	21.96	2.30	2.51	3.53
	A2	16-50	33.9	44.1	22.0	31.49	100	27.91	3.54	0.03	3.54
	Bw1	50-79	38.9	40.6	20.5	34.99	100	32.37	4.08	0.18	2.44
	Bw2	79-160	37.9	42.1	20.0	32.00	100	29.86	5.54	0.25	1.90
	C	160-183	41.9	35.1	23.0	22.22	100	20.71	7.10	0.18	1.33
	Cr	183-200	37.9	46.6	15.5	13.29	100	12.24	4.26	0.25	0.80

Table 3. Index values of the andic properties and selective dissolution analyses of <2 mm of soils of studied soils (%).

Profile	Horizon	Phosphate retention (%)	Volcanic glass (%)	Al _o +1/2Fe _o (%)	Water retention (% w/w)		Bulk density (g cm ⁻³)	2-0.02 mm Fraction (%)
					-33 kPa	-1500 kPa		
1	A1	34.35	9	0.07	18.6	15.9	1.52	54.3
	A2	35.11	10	0.14	20.2	17.6	1.48	52.7
	Bw1	35.36	7	0.26	22.8	17.3	1.36	53.4
	Bw2	38.52	5	0.28	23.1	17.8	1.66	54.7
	C	64.08	1	0.04	26.1	17.2	1.41	42.2
	Cr	68.12	1	0.02	27.5	18.0	1.4	40.9
2	A1	37.26	6	0.34	19.9	15.3	1.41	59.9
	A2	45.99	17	0.29	20.5	15.5	1.36	60.9
	C	74.20	3	0.02	25.1	13.0	1.32	80.7
	Cr	65.47	1	0.03	26.7	13.4	1.42	69.9
3	A1	32.45	13	0.69	23.8	13.4	1.59	57.8
	A2	38.27	6	0.61	27.5	15.5	1.45	51.2
	Cr	52.94	6	0.20	30.7	16.4	1.51	53.6
	R	-	-	-	-	-	-	-
4	A1	48.52	12	0.29	29.3	17.1	1.57	51.4
	A2	48.39	18	0.21	33.0	20.3	1.56	50.4
	Bw1	49.91	16	0.23	35.2	21.6	1.54	53.8
	Bw2	48.14	12	0.22	26.8	22.0	1.56	50.9
	C	79.76	3	0.12	25.0	20.1	1.35	55.2
	Cr	34.35	5	0.03	22.4	16.9	1.39	46.6
Profile	Horizon	Fe _d	Fe _o	Fe _p	Al _d	Al _o	Al _p	Si _o
1	A1	0.366	0.093	0.0042	0.038	0.026	0.023	0.141
	A2	0.510	0.219	0.0332	0.038	0.029	0.037	0.165
	Bw1	0.494	0.463	0.002	0.046	0.025	0.017	0.164
	Bw2	0.395	0.479	0.0022	0.037	0.043	0.029	0.140
	C	0.163	0.040	0.0014	0.015	0.020	0.021	0.099
	Cr	0.089	0.008	0.0014	0.013	0.018	0.029	0.071
2	A1	0.450	0.626	0.031	0.051	0.024	0.026	0.173
	A2	0.416	0.532	0.0479	0.046	0.028	0.038	0.161
	C	0.040	0.012	0.0014	0.007	0.014	0.027	0.046
	Cr	0.038	0.023	0.0013	0.008	0.018	0.023	0.058
3	A1	0.653	1.298	0.0281	0.057	0.037	0.042	0.265
	A2	0.789	1.145	0.0599	0.093	0.039	0.050	0.282
	Cr	0.430	0.316	0.0017	0.045	0.038	0.030	0.190
	R	-	-	-	-	-	-	-
4	A1	0.510	0.496	0.0247	0.045	0.042	0.036	0.212
	A2	0.565	0.341	0.0116	0.056	0.041	0.033	0.247
	Bw1	0.693	0.377	0.0498	0.055	0.041	0.044	0.255
	Bw2	0.509	0.348	0.0148	0.051	0.041	0.037	0.236
	C	0.315	0.170	0.0015	0.031	0.033	0.035	0.167
	Cr	0.176	0.021	0.0018	0.023	0.020	0.042	0.065

Table 4. The results of total element analysis and weathering indices of studied soil (%).

Pedon	Horizon	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	LOI	Total	CIA	PIA
1	A1	30.91	9.83	4.69	2.53	24.75	0.79	1.22	0.51	0.13	0.08	24.3	99.82	74,65	64,60
	A2	35.04	11.10	5.82	3.08	21.15	0.92	1.25	0.61	0.11	0.09	20.6	99.79	76,12	66,82
	Bw1	36.60	11.68	6.10	3.25	20.08	1.02	1.26	0.63	0.12	0.09	18.9	99.79	76,15	67,24
	Bw2	37.43	12.02	5.96	3.48	19.52	1.03	1.15	0.65	0.12	0.09	18.3	99.79	77,18	69,17
	C	18.72	5.72	3.16	2.27	36.28	0.37	0.51	0.31	0.06	0.04	32.4	99.83	76,33	68,94
	Cr	14.21	3.98	1.84	1.95	40.37	0.15	0.28	0.19	0.03	0.02	36.8	99.84	83,34	76,98
2	A1	34.16	10.92	5.32	3.56	21.47	1.09	1.21	0.58	0.14	0.09	21.2	99.79	74,60	65,63
	A2	33.10	10.45	5.29	3.54	22.91	1.02	1.06	0.57	0.12	0.08	21.6	99.79	74,68	66,46
	C	7.70	2.21	1.10	1.60	46.45	0.22	0.23	0.11	0.04	0.01	40.1	99.82	69,53	61,68
	Cr	10.70	2.78	1.34	1.57	43.99	0.27	0.30	0.14	0.06	0.01	38.7	99.83	70,06	61,86
3	A1	49.84	15.57	8.03	5.82	8.02	1.54	1.58	0.90	0.22	0.14	8.1	99.74	77,76	69,20
	A2	49.31	15.91	7.62	5.39	8.16	1.37	1.72	0.87	0.19	0.13	9.1	99.76	78,63	69,41
	Cr	31.03	10.10	4.65	3.11	24.85	0.70	1.18	0.53	0.12	0.07	23.4	99.80	76,25	66,58
	R	50.04	14.90	5.17	1.84	12.07	3.27	3.09	0.77	0.24	0.07	8.3	99.76	62,24	48,24
4	A1	44.81	13.88	6.10	3.75	11.68	1.21	1.67	0.70	0.53	0.12	15.3	99.79	77,16	67,09
	A2	45.62	14.58	6.39	3.69	10.95	0.96	1.86	0.72	0.40	0.11	14.5	99.78	78,88	67,96
	Bw1	44.84	14.50	6.35	3.73	11.57	0.89	1.77	0.72	0.23	0.10	15.1	99.80	79,71	69,15
	Bw2	41.57	13.27	5.90	3.95	14.71	0.78	1.57	0.66	0.17	0.09	17.1	99.80	79,63	69,41
	C	30.44	9.37	4.06	3.10	25.87	0.53	1.13	0.46	0.10	0.06	24.7	99.83	76,92	66,85
	Cr	17.61	5.07	2.31	2.12	37.29	0.25	0.65	0.25	0.05	0.03	34.2	99.84	76,88	66,19

Mineralogical properties

X-ray diffraction of the < 2mm fraction sand and clay fraction to determine the mineralogical properties of the profiles were undertaken in the study area and are shown in Figure 2 and 3, and infrared spectroscopy graphs are shown in Figure 4.

As seen from the figures, diverse phyllosilicates formed in diverse levels of crystallization and in differing amounts in the profiles. In the samples saturated with Mg in the profiles, the peaks, which are seen in the form of a plateau and are poorly crystallized between 14.5 and 15.9 Å, expanded to 17 to 21.2 Å in a Mg+Gl (glycerol) treatment, whereas in the case of K saturation, these peaks were close to a range of 10.6 and 14.5 Å. The peaks were seen at approximately 1.2 nm and approximately 1.4 nm in this application. The peaks were close to 10.7 to 12 Å when the K-saturated samples were heated. Especially with Mg applications, the peaks formed in a shoulder and were poorly crystallized. Therefore, the peaks indicated the existence of smectite and chlorite-smectite intermediate layer clays. The peaks that were seen between 9.99 and 10.13 Å

in all applications belonged to illite. The peaks that were seen between 7.10 and 7.20 Å in the samples saturated with Mg, Mg+Gl and K vanished when heated at 550°C. This indicated that these peaks belong to kaolinite. Significant differences were observed in the distribution of clays between the profile horizons. The distributions of clays in the profiles, except for Profile 4, in order of abundance were as follows: smectite, kaolinite, illite and chlorite-smectite as an intermediate layer, whereas the distribution observed in Profile 4 was kaolinite, smectite, illite and chlorite-smectite as an intermediate layer. While kaolinite and illite decreased with depth, the amount of smectite increased. In diffractions of the soil profile used to identify primary minerals, feldspar (anorthite and albite), amphibole and pyroxene (diopside, actinolite, tremolite, and hornblende) apatite, hematite, olivine and biotite were detected. Almost all of the primary minerals are composed of the aforementioned minerals. The IR spectrums were taken from the horizons to detect the presence of amorphous structures, such as allophane. As seen from these spectrums, peaks were identified in the mono, dimer and triple bond areas. The peaks were obtained in 712-798, 910-1027, 1409-1449, 1631-1643, 3355-3621 cm⁻¹ of the profile.

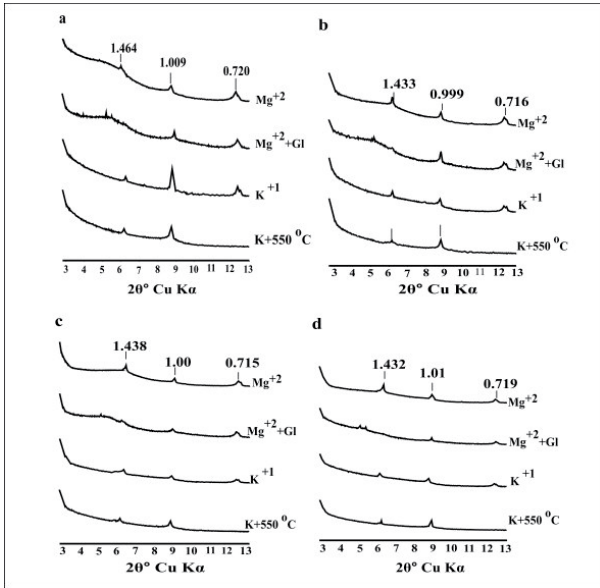


Figure 2. X-ray diffractograms of clay fractions of selected samples studied soils d values in nm. (a) A1 horizon of profile 1, (b) A1 horizon of profile 2, (c) A1 horizon of profile 3, (d) A1 horizon of profile 2.

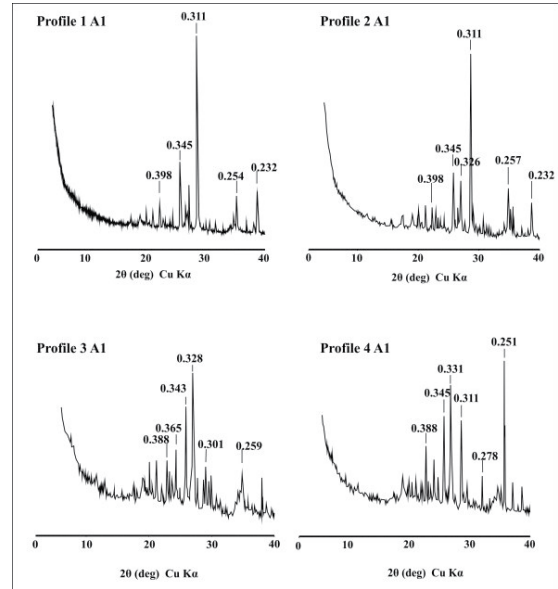


Figure 3. X-ray diffractograms of the upper horizons of all studied soils.

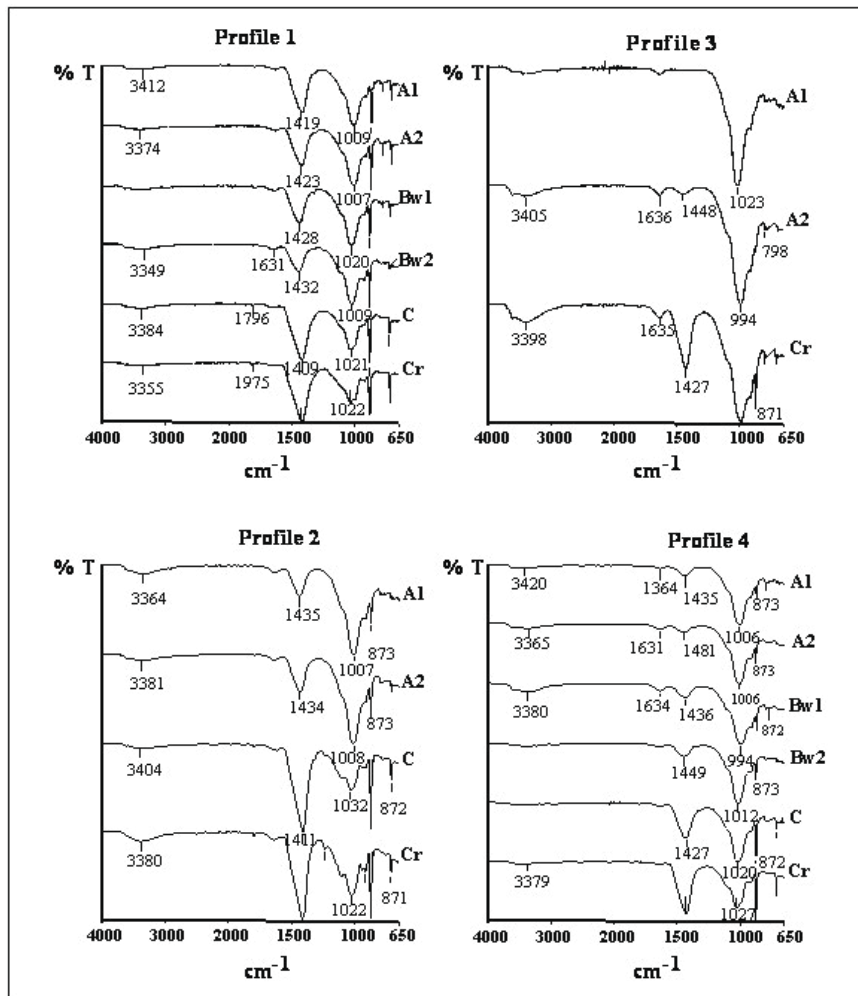


Figure 4. Infrared spectra of clay samples.

4. Discussion

Physical and chemical properties

The profile descriptions indicated that there are no diagnostic subsurface horizons whereas there was a weakly developed cambic horizon in profiles 1 and 4. The fact that there isn't a significant differentiation indicates that the parent material weathered weak; this finding, in turn, suggests that soil formation in the region is in its initial stage. Observation of a high rate of reaction with HCl in the profiles indicated that the primary C pool, which is released from minerals with plagioclase that are contained in basalts, turned into carbonates. As far as is known, basalt or andesite parent material cannot produce CaCO_3 . The high lime content detected in this study is due to basalt lavas absorbing some of the calcareous material underneath as they flow; Ca-containing minerals in basalt can be explained by the formation of CaCO_3 in a suitable environment and the crystallization of lime-rich hydrothermal waters in the foramina after the flow of basaltic lavas. As a matter of fact, similar to our findings, Dengiz and Şenol (2018) found that although the lining material in the study area was basalt, the amount of lime was high. The generally high content of sand in the soil, the sandy-loamy or sandy-clayey-loamy type of texture in the profiles in which the cambic horizon is absent, and the high sand content seen in the textured profiles indicated low weathering rate, in the soils; however, the increase in clay minerals in both the cambic horizons and C horizons, in profiles 1 and 4, suggested that the clay in these layers, which is comprised of neo-formation minerals, could be inherited from the parent material. The XRD results taken from the C horizon reveal that a significant amount of clay is present in this horizon. The relatively high clay content in the B horizon of profiles 3 and 4 emerged because of the alteration in the primary minerals into clay minerals. The clay minerals emerged as a result of the alteration of feldspars into clay minerals in basalts and andesite that are rich in feldspars and inherited to solum, depending on weathering. The reason that weathering was so low is climatic factors. Low precipitation, high evaporation, and a long dry season limited the weathering process. However, for the A and C horizons to form, 100 to 500 years must transpire in wet regions in Japan, and at least 1000 years is required for the A, B and C horizons to form (Yamada, 1968). Karacadağ, which formed on the soil that is present this study area, dates back to the Miocene-Pliocene. Despite this, climate has been the main factors restricting the formation of soil. The bulk density of the soil is lower on the surface and increases in the subsurface horizons. This results from the presence of organic matter on the surface. Furthermore, the fact that the C horizons are in the form of weathered or softened parent rocks has influenced the bulk density. For this reason, the bulk density increased with depth. The fact that the amounts of allophane and imogolite are low (according to index values of selective dissolution analysis) in these soils appears to be another factor responsible for the high bulk density (Wada, 1989). Andisols have a higher capacity for water retention due to the excessive amount of macro and micro pores. The high water retention capacity of andisols containing allophane and allophane-like amorphous minerals is due to the fact that these minerals contain fine particles and have a hollow spherical structure. (Wada, 1989). When the amount of water retention at -1500 kPa and at -33 kPa in the study area soils is compared with other Andisols in the world, it has lower values than expected. This situation may have been due the absence of allophane and imogolite or their very low presence because such materials as allophane and imogolite enhance the water retention capacity of volcanic soils due to their very small particle sizes and hollow spherical structures (Wilson et al., 1996). Because of the higher amount of clay in some horizons, a relatively higher water retention capacity has been detected in these horizons. This may be due to the fact that other clay minerals do not have allophane or similar materials. Soil organic materials are formed as a result of the decomposition of organic remnants by plant roots and microorganisms, and they are a critically important factor in mineral alteration. In this study, the organic matter in the soil, especially in the surface horizons, reached to 4.44 %. This value is very high level for arid areas of Turkey, but remained generally lower than the rates for humid areas. Low precipitation and a long and dry summer prevented the organic matter from reaching higher levels. Furthermore, the content of organic matter greatly decreased with depth. The organic matter was limited because of the low rate of clay content in most horizons and the scarcity of humus-metal complexes, which can be understood from the Al_p and Fe_p values because the humus-metal complexes and fine fractions protect organic matter from microbial decomposition and therefore,

improve its stability. High organic matter content caused an anti-allophanic effect to be limited because it hinders the bonding of Al and Fe by organic matter. However, despite low organic matter content, there is no allophane formation in these soils. The ΔpH ($\text{pH KCl} - \text{pH H}_2\text{O}$) was negative (-) in all horizons, and this indicated a negative charge in all horizons. In other words, there was no positive charge dominance. However, the pH values in NaF turned out to be over 9.5 in all horizons. The pH values in NaF were a quick test and indicated the presence of an amorphous material (Wada, 1989). Such anions as florid and phosphate undergo specific anion adsorption in allophane and imogolite, and they emit high amounts of OH^- to the environment when these minerals react with NaF. However, the test is only applicable to soils without free carbonates. These latter in the profile cause NaF pH values to measure high; therefore, the test involved isn't used to determine the mineralogy class in which the free carbonates are present. The presence of a net negative load in the soils in the area of the study and resulting $\text{pH}_{\text{NaF}} > 9.5$ due to carbonates indicates that there is no allophane or imogolite in the studied soils. Furthermore, another reason that the NaF test isn't always valid is that Al is attached to the organic matter. Nevertheless, the low content of organic matter in the soils and the very low Al_0 content make this factor less likely to be valid. Although the soils in the study area have a volcanic origin, a high CaCO_3 content was detected in the profiles. Several minerals with Ca, such as diopside, augite and plagioclase are present in the soils, which was evident from the primary mineral analysis of the soils in the study area. The high carbonate content in this location can be accounted for by the formation of CaCO_3 by the minerals. The CEC_s of these soils ranged from 6.6 to 34.99 (cmol kg^{-1}), and in certain areas, high values were obtained despite the low organic matter content. The rise in the CEC to such high values indicated the presence of alumina silicates (smectite) (Figure 2) with layers of high charge density. The phosphorous fixation capacities in all of the horizons remained above the required limits for Andisols (>85%). But it was relatively low compared with the other Andisols in the world. This is further evidence that the active forms of Al and Fe do not accumulate in the soil. The basic cations in the soil were aligned as $\text{Ca} > \text{Mg} > \text{K} > \text{Na}$ on the surface, in order of abundance. This shows that the feldspars that are found in the parent material are rich in Ca and Na. Consequently, the XRD results on the whole soil body (figure 3) indicated that the feldspars are plagioclases. The higher values of K on the surface soil were caused by its transportation through the plant cycle up to the surface. The base saturation was found to be 100% in all profiles. The fact that the base saturation was generally 100%, indicates that the low precipitation was insufficient for the bases to be leaching.

Total Element Contents

According to the total chemical analysis results, lower values were obtained in the total SiO_2 amount compared to silicate parent rocks that do not contain carbonate. Aluminum in the soil is directly related to the distribution of clay, and as the degree of decomposition in the soil increased, the amount of Al_2O_3 increased. The total Al_2O_3 in the studied soils reached values in the parent material that supported the low weathering rate. Considering all of these criteria, weathering during soil formation was concluded to occur slowly, and losses from and changes to the soil were deemed to be very limited. Indeed, CIA and PIA values indicate that Karacadağ profiles are moderately weathered. The decrease in weathering indices with depth indicates that weathering decreases with depth. In comparison to the total amount of Fe_2O_3 , the amount of free iron oxide was quite low in the study soils, and this indicates that weathering is low. This results from the poor weathering of hornblende. It is highly likely that the remaining iron was found in the crystal structure of the clays. There is no significant difference between the amounts of Na on the surface horizons in comparison with the Na amounts in the parent material of the profiles. This trend also applies to the other alkaline cations. In contrast, an increase was seen in the surface horizons in cations such as Na, K and Mg. This, in turn, demonstrates that weathering is limited and that alkaline cations aren't accordingly leaching. The increase in surface horizons is probably due to the elemental cycle due to herbal use. The total TiO_2 in the profiles ranges from 0.11% to 0.90%. The distributions of this element in all of the studied profiles in solum were close to each other and very small. The percentage of TiO_2 , which is a durable element, indicated the soil weathering rate. This element, the amount of which increases with soil development, exhibits low values that parallel the slow pedogenic development in the study area soils.

Selective dissolution analysis

The Al, Fe and Si values determined with a selective solution analysis offered significant data to determine the composition and amount of minerals formed in volcanic soils. Index values of selective dissolution analysis are presented in Table 5. Index values, obtained with the help of these data, gave an idea about whether amorphous materials such as allophane, imogolite and ferrihydrite were available or not. Although the Fe_o , Al_o and Si_o values determined in the acid oxalate in the study area reached high levels in some of the horizons, these values were below those seen in Andisols that are rich in allophane. Therefore, these low values indicated a low level, or total absence of amorphous compounds such as allophane and imogolite. Dahlgren (1994) reported that, in cases where the amount of Si_o is less than 0.2, allophane should not be taken into consideration, explaining that acid oxalate may require quite few O_2 and Si from the surface of the crystal minerals because of special circumstances. Al_p and Fe_p extracted from pyrophosphate provided significant information about organometallic complex forms of Fe and Al. While this value is high in Andisols, it is observed at very low levels in the soils of this study. Because low precipitation and the long and dry summer season in the study area prevent the organic matter from reaching high levels, the Fe_p , Al_p values also were observed to be low.

The solubility of Al and Fe staying low when the pH was over 5.5 had a large impact (Lindsay, 1999). Parfitt and Saigusa (1985) reported that allophane and imogolite are dominant between a moderate acid and neutral pH, whereas Al-humus complexes can exist in more acidic circumstances (pH<5.5). Therefore, the low organic matter content and high pH levels in the study area soils have, to a large extent, prevented the formation of Fe-Al-humus complexes when compared with Andisols. However, the Al_p values in the study area, in the surface horizons, were observed to be higher than those of Al_o and Al_d . This indicates that the Al-complexes were found in profiles at a higher rate than allophane or crystallized Al compounds or reached significant amounts. If the rate of Fe_p/Fe_o was between 0.9 and 1.6, this indicated metal-humus complexes. This rate was below 0.9 in all of the horizons, which indicated the limited presence of Fe resulting from metal-humus complexes or Fe humus complexes were identified far less than the other Fe fractions. The Fe_d rates in the studied profiles appeared to be generally higher than in the other extracts. Furthermore, the Al_d values were higher than the general Al_o . This indicated that Al was identified more often in crystallized compounds than in allophane. High Fe_d values indicate that Fe is found in the form of crystallized compounds. The low Fe_o/Fe_d rates seen in the profiles support this conclusion. Ferrihydrite is

one of the amorphous forms of iron, and it is under the combined effect of high and steady precipitation, and the impact from the organic matter content, which affects crystallized iron distribution as well as the high Al activity in acidic conditions. The Fe_p/Fe_d values in the soils were also fairly low. Such low values are additional evidence of the presence of crystallized Fe compounds. The rate of $(Al_p - Al_o)/Si_o$ can be used to identify the formation of allophane and imogolite in volcanic soils. This ratio varies in most volcanic soil between 1 and 2.5; if it is close to 1, it signifies allophane, and if it is close to 2, it signifies imogolite (Parfitt and Wilson, 1985). This ratio is not within such limits as to reveal the presence of allophane or imogolite in any of the studied profiles, and it has generally turned out to be negative (-) in the horizons (Table 7). If this value is smaller than 0.75 or greater than 2.4, this finding indicates the absence of minerals with amorphous Al. Additionally, the Al_p/Al_d values in the soil are used as a criterion for Andisols, and this value is above 0.9 in Andisols. The Al_p/Al_d values in the profiles appeared to be higher in some horizons than 0.9. However, because the other index values do not confirm the presence of allophane, this value alone does not make sense. It only shows that Al is bonded to a significant amount of organic matter. Likewise, the Al_p/Al_d values are definitive for Andisols; if this value is below 0.1, it signals the presence of allophane. In all of the studied profiles, the Al_p/Al_d values were observed to be above 0.1. If this value is above 0.1, this indicates that there is no allophane and that a significant part of the aluminum is retained by the Al-humus complexes. Consequently, very low rates of Al_o and Si_o caused the formation of alumina silicate minerals through neo-formation compared with Fe_p , leading to the depletion of Al and Si, which were released into the environment through weathering. Considering the low phosphorus fixation, low amounts of Al_o and Si_o were seen to have prevented allophane formation. Shoji and Fujiwara (1984) reported that allophane was, to a large extent, linked to the pH of the soil and formed when the pH was between 5 and 7. Particularly high organic matter, and the reduction in silica loss due to low precipitation and adsorption of Al by organic matter reduced the formation of allophane (anti-allophonic effect). Low precipitation and a long dry season in the study area caused the loss of Si to be low, and insufficient Al emerged because of low weathering. As a result of the formation of secondary Alumina-silicate clay minerals through neo-formation, the heavy use of Si and Al and the presence of organic matter over 2% in the surface horizons led to the formation of Fe-humus complexes, significantly preventing allophane formation. Many researchers such as Moustakas and Georgoulas (2005), reported that in ustic, xeric and aridic moisture regimes, allophane is rarely found because of the restriction on silicate loss.

Table 5. Index values of selective dissolution analysis of the studied soils.

Pedon	Horizon	$(Fe_d - Fe_p) \times 100 / Fe_o$	Fe_o/Fe_d	Fe_d/Fe_p	Fe_p/Fe_o	Fe_p/Fe_d	$(Al_p - Al_o) / Si_o$	Al_p/Al_d	Al_o/Al_d	Al_p/Al_o
1	A1	74.59	0.254	0.078	0.045	0.011	0.02	0.61	0.68	0.88
	A2	57.06	0.429	0.088	0.152	0.065	-0.05	0.97	0.76	1.28
	Bw1	6.28	0.937	0.081	0.004	0.004	0.05	0.37	0.54	0.68
	Bw2	-21.27	1.213	0.066	0.005	0.006	0.10	0.78	1.16	0.67
	C	75.46	0.245	0.052	0.035	0.009	-0.01	1.40	1.33	1.05
	Cr	91.01	0.090	0.048	0.175	0.016	-0.15	2.23	1.38	1.61
2	A1	-39.11	1.391	0.085	0.050	0.069	-0.01	0.51	0.47	1.08
	A2	-27.88	1.279	0.079	0.090	0.115	-0.06	0.83	0.61	1.36
	C	70.00	0.300	0.036	0.117	0.035	-0.28	3.86	2.00	1.93
	Cr	39.47	0.605	0.028	0.057	0.034	-0.09	2.88	2.25	1.28
3	A1	-98.77	1.988	0.081	0.022	0.043	-0.02	0.74	0.65	1.14
	A2	-45.12	1.451	0.104	0.052	0.076	-0.04	0.54	0.42	1.28
	Cr	26.51	0.735	0.092	0.005	0.004	0.04	0.67	0.84	0.79
	R	-	-	-	-	-	-	-	-	-
4	A1	2.75	0.973	0.084	0.050	0.048	0.03	0.80	0.93	0.86
	A2	39.65	0.604	0.088	0.034	0.021	0.03	0.59	0.73	0.80
	Bw1	45.60	0.544	0.109	0.132	0.072	-0.01	0.80	0.75	1.07
	Bw2	31.63	0.684	0.086	0.043	0.029	0.02	0.73	0.80	0.90
	C	46.03	0.540	0.078	0.009	0.005	-0.01	1.13	1.06	1.06
	Cr	88.07	0.119	0.076	0.086	0.010	-0.34	1.83	0.87	2.10

Mineralogical properties

The presence of kaolinite and illite in the profile indicates that the feldspars turned directly into kaolinite and illite, most likely due to mineral weathering at hydrothermal conditions. There is no significant difference in the amount of minerals that exist deep in the profile. The similarity of the minerals to one another in the solum and the lack of significant differentiation in their amounts indicated that these soils at initial stage of development, but the prevalence of clay minerals with an intermediate layer in the solum demonstrated that the profile has a more developed composition than during primary stages. However, in proportion to the total iron oxide, the rate of free iron oxide that has weathered, and thus passed into a free state, was low in well-developed soils. Illite, which was encountered in all profile horizons, probably formed through the conversion of minerals that contain. The fact that the illite was almost uniform in the profile supports the view that it was formed from feldspars that are commonly found in basalts and andesite. Fitzpatrick (1975) noted that feldspars could form illite in conditions similar to those of our study. The amount of illite increased, although minimally, as the depth increased in some of the profiles. This finding suggests that weathering in the profile is not at an advanced stage. The reason that illite may be less available in the upper horizons can be explained by the low weathering possibility in deep soil as well as by the formation of the form of illite \rightarrow K \rightarrow smectite conversion in this profile. Smectite formed in an environment where the base saturation and, particularly the Mg content, were high; it is found as a permanent mineral here. According to a large number of researchers (Yeşilsoy and Kapur, 1982; Poulencard et al., 2003; Parfitt and Wilson, 1985; Parfitt and Kimble, 1989; Shoji, 1986), if the rate of Si/Al in the soil solution is higher than 2, smectite is formed in a neutral-weak acidic pH, high Ca+Mg and Na dilutions (Carson et al. 1976). It has been suggested by many researchers (Yeşilsoy and Kapur, 1982; Parfitt et al., 1980; Murray et al., 1977; Shoji, 1986; Wada, 1989) that the presence of significant amounts of calcium will promote the formation of smectite clay minerals in arid regions but that it will hinder the formation of kaolinite (Yeşilsoy and Kapur, 1982). There is some controversy regarding the formation of clay minerals of type 2:1 in volcanic soils. The formation of clay type 2:1 in the study area reached a significant level. This finding is observed because the basic cations, which emerged from the weathering of pyroxene and amphiboles, raised the pH, and because the Si and Ca could not be sufficiently leached, encouraging smectite formation accompanied by a high Si/Al ratio and Ca. The presence of such minerals as augite and diopside (Figure 3), which are among the primary minerals, reinforces this theory. In light of all of these data, the clay minerals in the studied soils formed as products of conversion and weathering of the minerals, feldspars, pyroxene and amphibole, which are heavily detected in basalt and andesitic materials derived from the parent material. As primary minerals, feldspar (anorthite and albite), amphibole, pyroxene (diopside, actinolite, tremolite, and hornblende) apatite, hematite, olivine and biotite were identified in the soils (Figure 3). The primer mineral analysis indicated that the feldspars are plagioclases which are the most found minerals in mafic materials. Ferro minerals, such as hematite, were detected in the profiles (Figure 3). Wada (1987) reported that hematite is related to magnetite and maghemite, that magnetite can easily formed from maghemite under forest vegetation and in the presence of organic matter and that gibbsite is available in well-disintegrated volcanic ash soil in Hawaii. In the IR spectrums of the samples, tension peaks that belong to structural OH were obtained between 3355 and 3621 cm^{-1} in the form of a large strip belonging to an H bond. Curve vibrations that belong to H were obtained at approximately 1631 to 1643 cm^{-1} , whereas vibrations belonging to the Si-C single bond were found at 712 to 798 cm^{-1} . Allophane-like minerals were found in the soil in four profiles. Vibrations were detected at 2800 to 3800, 1630 to 1640, 975 to 1020 and 800 to 400 cm^{-1} . Such vibrations could not be obtained in the study area. However, the finding of Si-C single bonds at 790 cm^{-1} and again the discovery of amorphous silicate at 1636 cm^{-1} were the characteristic peaks. The very high sand fraction in the soil profiles and the availability of A-C or A-Bw-C horizons in the profiles revealed that the time of soil formation has representing present disintegration was short, that the weathering in the profiles was gradual and that the effect of the parent material was strong. As low precipitation and a dry summer restricted the loss of Si in the soil, no allophane or imogolite formation was observed. Especially the fact that the clay mineral types in the clay fractions in the Horizons remain the same and the amounts and types of primary minerals are similar indicates that pedogenic differentiation occurs quite slowly.

Andic properties and classification

Requirements for a soil to be classified as Andisols are described in Soil Survey Staff (2014). Two items in these requirements cannot be met in any of the profiles. The first 3 requirements given in item number 3 are seen only in profile 3. The index values belonging to the andic properties for the studied soils can be seen in Table 4 and 5. The $\text{Al}_0 + 1/2 \text{Fe}_0$ values in all of the profiles are rather low and below 0.71 % in all of the horizons. Although this value alone can meet the requirements of several items mentioned above in some of the horizons, it remains insufficient for andic properties when evaluated along with the other properties. Phosphate retention in the soils is lower than 85 %, and it shows that active Al and Fe complexes do not accumulate in the soil. The bulk density was higher than 0.9 gr/cm^3 in all of the horizons. For this reason, the studied profiles do not meet the criteria given in item number 2. The criteria given in item number 3 were also used for classifying the soils, which are not only formed on volcanic deposits but also on other deposits, which exhibit andic properties and are not volcanic. Although the sand+coarse silt fraction (0,02-2 mm) was over 30 percent in all of the studied profiles and the phosphate retention in the first profile was over 25 %, the $\text{Al}_0 + 1/2 \text{Fe}_0$ and volcanic glass content of the studied samples in the other profiles, except Profile 3, did not meet the requirements in item number 3. In Profile 3, the volcanic glass content was between 3 and 16 % and did not meet the requirement of $[(\text{Al}+1/2\text{Fe}) \text{ percentage} \times (15.625)] + [\% \text{ volcanic glass}] = 36.25$ or the further demands of item "3e"; therefore, none of the studied profiles can be classified as Andisols. Profile 2 is classified as Vitrandic Haploxerolls sub-group of Mollisols ordo because contain mollic epipedon and it is in a Xeric moisture regime and meet the necessary requirements for the vitrandic subgroup. Because profile 3, studied in light of these data, do not contain any other diagnostic horizons apart from ochric epipedon, it is classified as Orthent sub-ordo of Entisol ordo. Due to it is in a xeric moisture regime and meet the necessary requirements for the vitrandic subgroup, it is classified as Vitrandic Xerorthent, whereas in profiles 1 and 4, are in the Inceptisol order because of the existing of a cambic horizon in both profiles; because they do not contain plagen and antropic epipedon, they are classified in the subgroup xerept; finally, because of not involving a duripan, calcic or petrocalcic horizon and fragipan as well as having a base saturation of over 60 %, they are in the group Haploxerept great group. They are classified as Vitrandic Haploxerept at the sub-group level.

Conclusions

In this study, four profiles that formed on volcanic parent material in semi-arid climatic in Central Anatolia around Karacadağ were described. The physical, chemical and mineralogical properties of the profiles were identified and it was determined whether the soils formed in the study area could be classified as Andisols. The soils in the study area were still in an initial stage of development. Among the studied profiles, ochric epipedon was identified in profiles 2 and 3, whereas no diagnostic horizon other than cambic B was identified in addition to mollic and ochric epipedon. The low precipitation and long and dry summer in the study area restricted the accumulation of organic matter, adversely affected weathering, and wholly affected amorphous materials such as allophane and imogolite by delaying the leaching of Si and partly affecting the formation of Fe-humus complexes. However, a significant amount of aluminum in the profile was still determined to be attached to the organic matter. Of the phyllosilicates that were studied, smectite kaolinite, illite and chlorite-smectite were the most common minerals. The leading primary minerals in the soil were identified as feldspar (anorthite and albite), amphibole and pyroxene (diopside, actinolite, tremolite, and hornblende), apatite, hematite, olivine and biotite. Although the studied profiles formed on volcanic parent material, they were not classified as Andisols. Profiles 2 and 3, which were obtained from the study area, were classified as Vitrandic Haploxerolls and Vitrandic Xerorthent respectively, and profile 1 and 4 were classified as Vitrandic Haploxerept. From the obtained data, we established that the climate determines the concentration of such cations as Al, Si, and Fe in the soil solutions by affecting the accumulation of organic matter and the amount of weathering products from volcanic materials in the formation of andic properties, as described in Soil Taxonomy 2014; therefore, the climate drives the formation of amorphous minerals. In conclusion, this study reveals that climate is an important factor in Andisol formation, in addition to the glassy material content of the parent material.

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