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NOTE

VARIATION IN SOIL CLAY MINERALS OF SEMI-ARID REGIONS OF FARS PROVINCE, IRAN

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ABSTRACT

Transformation and neoformation of clay minerals as affected by various physiographic positions were studied in soils from semi-arid regions of Fars province in southern Iran. Soil samples were taken from control sections of soil profiles at various physiographic units. Clay specimens were prepared from soil samples. The clay mineralogy of specimens was analyzed by X-ray diffraction. Mica (illite), chlorite, smectite (montmorillonite), vermiculite, palygorskite, and interstratified illite-smectite and chlorite-smectite were recognized. The higher physiographic units contained more illite and chlorite, whereas the lower ones had a higher montmorillonite and palygorskite. This was further confirmed by changes in cation exchange capacity of soils. Inherited illite and chlorite were transformed to montmorillonite and vermiculite. It is possible that neoformation of montmorillonite and palygorskite from soil solutions has also occurred.

Key words: Clay minerals, Neoformation, Physiographic units.

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دگرگونی کانی های رسی خاک های مناطق نیمه خشک استان فارس، ایران

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چکیده

تغییر شکل و تشکیل مجدد کانی های رسی خاک های واحدهای مختلف فیزیوگرافی در مناطق نیمه خشک استان فارس مطالعه شد. شناسایی کانی های رس به روش پراش پرتو رنتگن(XRD) روی نمونه های خاک که از بخش کنترل پروفیل خاک در هر واحد فیزیوگرافی تهیه شده بود انجام گرفت. وجود میکا (ایلیت)، کلریت، اسمکتیت (مونت موریلونیت)، ورمیکولیت، پالی گورسکیت و کانی های مخلوط ایلیت-اسمکتیت، و کلریت- اسمکتیت در این خاک ها تشخیص داده شد. خاک های واحدهای فیزیوگرافی مناطق مرتفعترحاوی مقادیر زیاد ایلیت و کلریت بوده درحالی که مناطق پست تر دارای مونت موریلونیت و پالی گورسکیت بیشتری بودند. اندازه گیری ظرفیت تبادل کاتیونی نیز این یافته ها را تایید کرد. بیشتر رس های ایلیت و کلریت در این خاک ها موروثی بوده و بتدریج به مونت موریلونیت و ورمیکولیت تغییر شکل می دهند. در این خاک ها امکان نوسازی رس های مونت موریلونیت و پالی گورسکیت از محلول خاک نیز وجود دارد.

INTRODUCTION

Effects of types and amounts of clay minerals on behavior and physico-chemical properties of soils have been studied by several workers (2, 5, 14, 18, 22, 29). It seems that due to low weathering processes in semi-arid regions, illite and chlorite are the only types of clay minerals that exist in soils. But, some research on clay mineralogy of soils of Middle East showed that minerals of clay were similar to those of humid regions (12, 21). The importance of clay minerals in soils and their related behavior and properties on one hand, and the role of topography on the genesis of soils in semiarid regions on the other hand, led to the investigating of evolutionary relationships in the semiarid Fars province. Soil mineralogy-landscape relationships and subsequent changes in clay minerals have been reported earlier (6, 10, 35, 37). Mica and chlorite have been reported (10) as the major inherited clay components in soils of Dasht-e-Arjan, Iran, which are transformed to other clay minerals such as smectite, vermiculite, and palygorskite. Abtahi (1) reported that the amount of smectite in saline soils of lowland area was higher than that of palygorskite, whereas upper plateaus and piedmont plains contained more palygorskite. Such changes could be referred to as dynamic interactions between soil properties and landforms, i.e. pedogeomorphology (8) in which the catenary hydrological conditions are reflected by variations in water retention and transmission. Such differences are manifested in catenary variations of individual mechanisms as well as in kind, amount and balance of pedological processes. In addition, K uptake by plants could transform clay minerals (15, 36).

In this study investigations were made on the soils of catenary sequences in Fars province, in order to determine what, if any, changes in clay minerals occurred in various physiographic units.

MATERIALS AND METHODS

Generally, Fars province with the mean annual precipitation of 300 mm and the average air temperature of 15 °C is classified as a semiarid region with ustic and hyperthermic soil moisture and temperature regimes, respectively. Soils of the study area are developed on limestone of late Tertiary and Quaternary ages. Irrigated agriculture, dryland farming and pasture are three common land uses of the region. On the catenary sequences at different parts of Fars province, (Fig. 1), different physiographic units, i.e. alluvial-colluvial fans, plateaus, piedmont alluvial plains, flood plains, upper terraces, river terraces, and lowlands were selected. On each unit, a representative soil profile was dug, and soil samples were taken from control sections for various analyses. Detailed soil survey reports for the study area were given in 8 M.S. theses (9, 19, 23, 26, 28, 30, 39, 40).

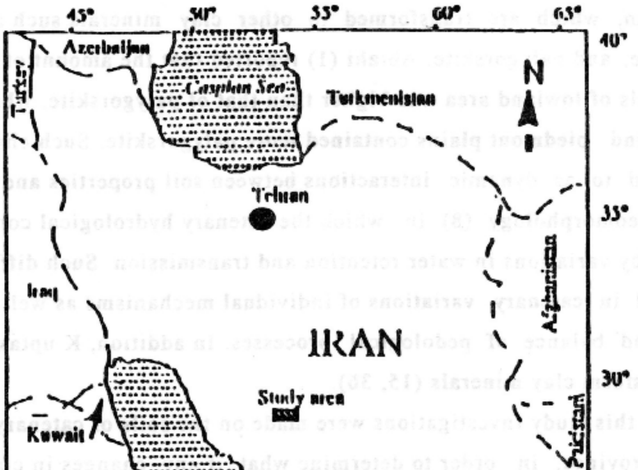


Fig. 1. Location map of Fars province, the study area.

Clay fractions were separated from the < 2 mm soil samples (20, 24). X-ray diffraction (XRD) was done on a Philips PW 1130 diffractometer with Cu Kα radiation (40 kV and 20 mA). Oriented specimens of the <2-mm fractions were prepared by suction onto ceramic plates. They were saturated with magnesium and potassium by repeated addition of 1 M $MgCl_2$ and 1 M KCl solutions, respectively. The oriented samples were scanned from 2 to 30 °2θ for the Mg-saturated and air-dried, Mg-saturated and glycerol-solvated, K-saturated and air-dried, and K-saturated and heated to 550 °C. Clay mineral d-spacings were distinguished on the XRD peaks. Palygorskite was identified with the help of electron micrographs taken by Philips SM 300 Transmission Electron Microscope (TEM). Estimation of clay mineral proportions was semi-quantitatively obtained using the *"001"* peak intensities of the Mg-saturated and glycerol-solvated samples (17). Cation exchange capacity was determined as outlined by Chapman (7) and free iron oxides of clay particles were also determined by procedure of Mehra & Jackson (24).

RESULTS AND DISCUSSION

Classification and physico-chemical properties of soils of physiographic units revealed the semi-arid climatic condition prevailing in the study area (Table 1). The ustic soil moisture regime is common in almost all soils. Soil horizons and their thickness were different in various physiographic units. As shown in Table 1 a 20 cm A1 horizon occurred over the parent material in unit 1, i.e. alluvial-colluvial fans, whereas deeper soils with more horizon differentiation occurred in the other units. This indicates that the weathering processes were more effective in soils of the lower physiographic units. These differences were reflected in greater transformation of the inherited clay minerals in soils of the lower physiographic units (Table 2). Peaks for mica

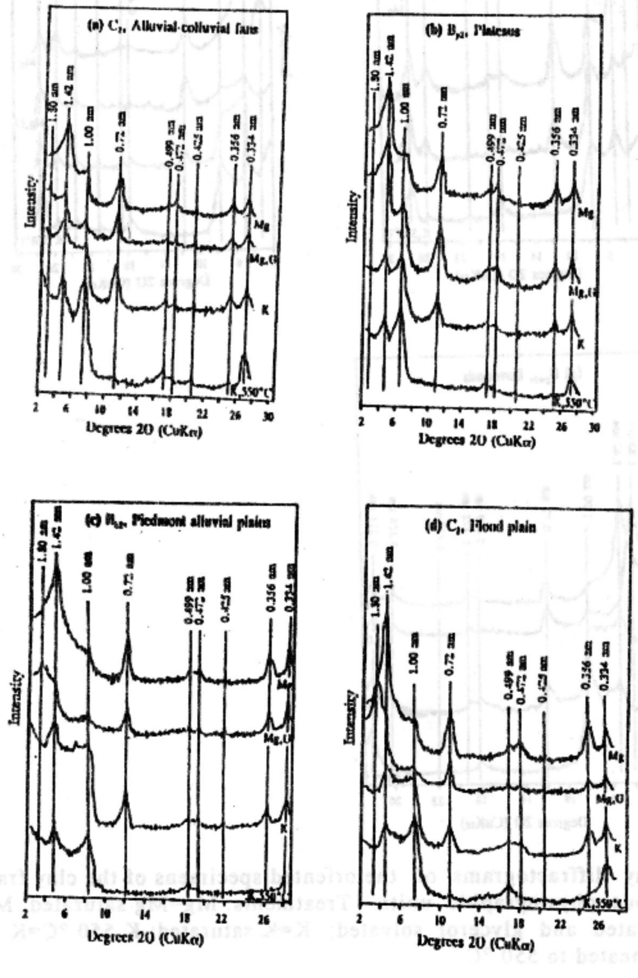
Table 1. Classification and physico-chemical properties of soils of various physiographic units.

Units[†]	Horizon	Depth	Sand	Silt	Clay	Texture[§]	pH	EC	SP	CCE	OC	CEC
		cm						dSm^{-1}	←	%	→	cmol kg^{-1}
				Loamy-skeletal, carbonatic, hyperthermic, Aridic Ustorthents								
1	A_1	0-20	49	38	13	l	7.6	0.4	33	35	0.1	-
	C_1	20-50	59	28	13	sl	7.7	0.4	30	37	0.0	-
	C_2	50-150	57	29	14	sl	7.4	0.5	43	42	0.0	8.7
				Fine loamy, gypsic, hyperthermic, Aridic Ustochrepts								
2	A_p	0-20	30	45	25	l	7.4	2.4	46	30	0.7	-
	B_{y1}	20-60	42	35	23	l	7.5	2.2	44	18	0.5	-
	B_{y2}	60-100	40	40	20	l	7.7	2.9	38	25	0.3	14.5
				Fine carbonatic, hyperthermic, Haplocalcidic Ustorthents								
3	A_p	0-30	13	49	38	sicl	7.5	5.4	55	41	1.1	-
	B_{k1}	30-65	11	48	41	sic	8.1	2.3	62	42	0.7	-
	B_{k2}	65-125	11	49	40	sic	8.2	3.2	60	44	0.2	13.2
				Fine carbonatic, hyperthermic Aridic Ustorthents								
4	A_p	0-20	14	41	45	sic	7.5	0.7	47	43	0.5	-
	C_1	30-55	16	35	49	c	8.2	0.3	47	42	0.2	16.8
	C_2	55-140	20	37	43	c	8.0	0.3	53	41	0.1	-
				Fine Loamy carbonatic, hyperthermic Aridic Ustorthents								
5	A_p	0-20	28	49	23	l	7.7	0.8	33	53	0.4	17.4
	B_1	20-40	25	46	29	cl	7.9	0.5	39	55	0.3	-
	B_2	40-135	24	48	28	cl	8.1	0.5	48	53	0.1	23.9
				Fine Loamy carbonatic, hyperthermic Typic Haplocalcids								
6	A_p	0-15	33	38	29	cl	7.4	1.5	48	13	0.4	-
	Bw_1	15-40	35	34	31	cl	7.3	1.2	47	29	0.2	-
	Bk_2	40-100	29	43	28	cl	7.2	1.2	45	50	0.1	10.0
				Fine carbonatic, hyperthermic, Fluvaquentic Endoaquolls								
7	A_{pg}	0-25	23	35	42	c	8.1	3.4	61	39	4.9	30.4
	B_{gw1}	25-50	15	32	53	c	8.2	1.4	53	39	1.8	-
	B_{gw2}	50-100	23	34	43	c	8.1	1.1	50	41	1.2	18.4

† 1=Alluvial-colluvial fans; 2=Plateaus; 3=Piedmont alluvial plains; 4=Flood plains; 5=Upper terraces; 6=River terraces; 7=Lowlands.

§ l=·Loam; sl= Sandy loam; sicl= Silty clay loam; sic= Silty clay; c= Clay; cl= Clay loam.

(illite), chlorite, smectite (montmorillonite), vermiculite, interstratified illite-smectite and chlorite-smectite, and palygorskite were recognized on the X-ray diffractograms for the clay particles (Fig. 2). Illite was identified by the presence of the "*001*" reflections at 1.0-nm and 0.33 nm which remained unaffected by various treatments, but an increase in its sharpness on glyceration



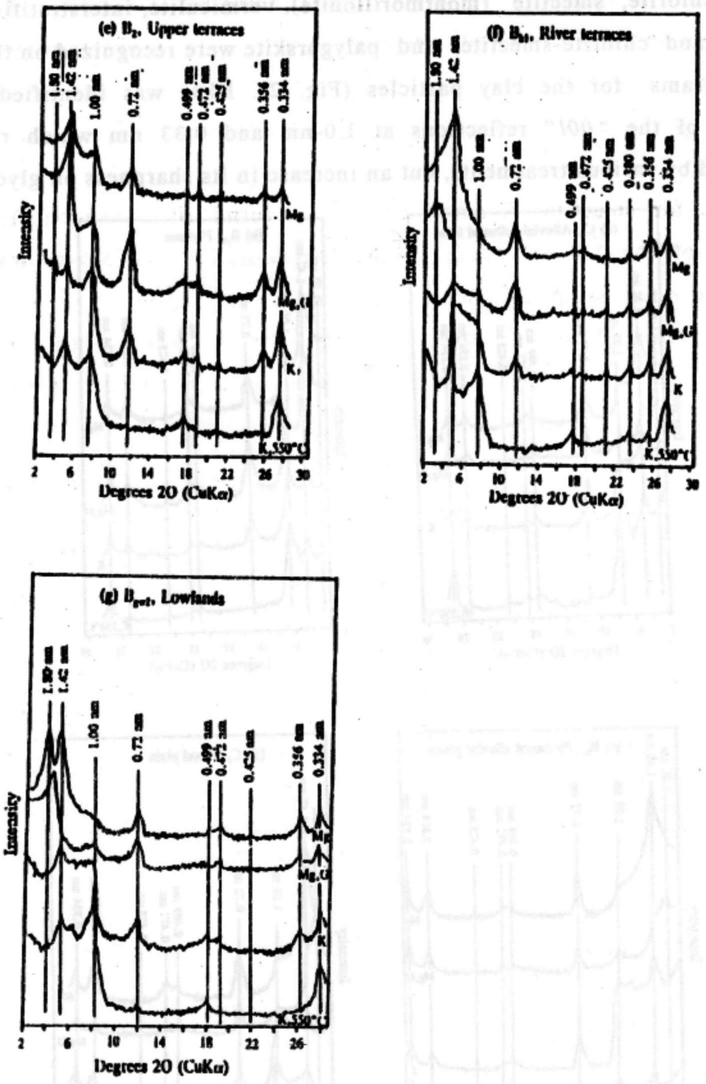


Fig 2. X-ray diffractograms of the oriented specimens of the clay fractions of various physiographic units. Treatments: Mg=Mg saturated; Mg,G=Mg saturated and glycerol solvated; K=K saturated; K,550 °C=K saturated and heated to 550 °C.

suggests interstratification of illite with expanding clay minerals. Chlorite and chlorite-interstratified minerals were identified by the peaks at approximately 1.4 nm, 0.7 nm, 0.47 nm, and 0.35 nm ("*001*" "*002*" "*003*" and "*004*" reflections, respectively) in samples saturated with K and then heated to 550°C. A peak at 1.8 nm in samples saturated with Mg and glycerol-solvated is diagnostic for smectite. A small amount of vermiculite was identified by the presence of the 1.4 nm peaks in the Mg-saturated, and Mg-saturated and glycerol-solvated samples. The 1.4 nm peak of vermiculite collapsed to 1.0 nm in the K-saturated when heated to 550° C. Strong "*001*", "*002*", *and* "*003*" reflections at 1.05, 0.64, and 0.54 nm, respectively are diagnostic for palygorskite. Moreover, palygorskite presence was evidence by electron micrographs (Fig. 3).

Table 2. Types and proportions of clay minerals in various physiographic units of the study area.

Units[†]	Illite	Chlorite	Vermiculite	Smectite	Palygorskite
1	++++++[§]	+++++	ND	++	++
2	+++++	++++	+	++++	++++
3	++++	+++++	++++	+	++++
4	++++	++++	++	+++++	++++
5	++++	++++	++	+++++	++++
6	++++	++++	+++	++++++	+++
7	++++	++++	+++	++++++	+

[†] 1= Alluvial-colluvial fans; 2= Plateau; 3= Piedmont alluvial plains; 4= Flood plains; 5= Upper terraces; 6= River terraces; 7= Lowlands.

[§] ND= not detected; += 1-2%; ++= 3-5%; +++= 6-10%; ++++= 11-20%: +++++= 21-40%; ++++++= 41-60%.

Different proportions of similar clay minerals were found in soils of various physiographic units (Table 2). Analysis of < 2-µm fractions showed that illite and chlorite are major components and are common to all soils. Substantial amounts of these minerals were found in soils of upper units, i.e. alluvial-colluvial fans (Fig. 2-a), but towards the lower units, i.e., piedmont plains, flood plains, terraces, and lowlands (Fig. 2b through 2g, respectively).

Montmorillonite and palygorskite were found in substantial amounts. As Suarez (34) showed, weathering of mica in Mg-rich soils could cause the formation of interstratified illite-smectite-palygorskite minerals. Such intermediate clay minerals will change to palygorskite later in time. However, the intensity of the 1.8 nm peak (montmorillonite) was lower, and that of the 1.0 nm (illite) and 1.4 nm (chlorite) were higher for the samples taken from the upper units. The above-mentioned intensities for illite and chlorite decreased in soils towards the lower units. These changes were confirmed by cation exchange capacity for the <2-µm fractions (Table 3). The CEC for upper and toward lower units was 46 and 72 $\mathrm{cmol_{(+)}kg^{-1}}$, respectively.

Fig. 3. Trans mission electron micrograph of the clay fractions. The fibrous needle-shape materials represent palygorskite.

Table 3. Cation exchange capacity (CEC) and free iron oxides of the clay fractions taken from selected horizons of various physiographic units.

Units[†]	Horizon	CEC $cmol_{(+)}\,kg^{-1}$	Free Fe_2O_3 %
1	C2	46	2.2
2	B_y2	54	2.0
3	B_k2	64	3.1
4	C1	27	0.6
5	B2	45	3.1
6	B_k1	44	2.6
7	$B_{gw}1$	72	2.2

[†] 1= Alluvial-colluvial fans; 2= Plateaus; 3= Piedmont alluvial plains; 4= Flood plains; 5= Upper terraces; 6= River terraces; 7= Lowlands.

Changes occurring in type and proportion of clay minerals have been related to the hydrological properties of different physiographic positions (37, 38). No significant changes were found in the minerals of the upper units. It seems that the large portions of illite and chlorite in such units were inherited from slightly weathered parent materials (10, 22, 33). A more suitable weathering condition of piedmont alluvial plains and of upper terraces was confirmed by higher amounts of free iron oxide which increase from 2.0% in plateaus to 3.1% in piedmont alluvial plains and upper terraces (Table 3). Lower percentages of iron oxide in flood plains and lowlands (0.6% and 2.2%, respectively, Table 3) may have resulted from waterlogging and gleization which have reduced ferric oxide to ferrous oxide. The latter is more mobile and hence might have imigrated from the gleyed horizons and leached out from the solum by the natural drainage.

It seems that illite and chlorite were transformed to montmorillonite in the middle positions of the sequence. In such units, namely the translocation zones (8), surface and subsurface water movements caused K depletion from illite (11, 27) and removed Fe, Mg, and hydroxyl groups from octahedral layers of chlorite (4, 22). On the XRD pattern for the Piedmont alluvial plains (Fig 2-c), the presence of peaks at 1.36, 1.42, and 1.52 nm in Mg-saturated and glycerol-solvated samples demonstrated the hydroxy -Al and -Mg and interlayered montmorillonite, respectively, and suggested that transformation of illite and chlorite has occurred (3, 6, 16, 34). Uptake of K by plant roots has probably accelerated the rate of such transformations (15, 36).

Since substantial amount of palygorskite was found only in the middle units, neoformation of this mineral from Mg- and Si-enriched soil solutions (25, 31, 32, 34) has probably occurred. This is induced from the highly probable occurring processes of weathering of mica which release K and Al. Such ions in the Mg-rich soils with Si could cause the formation of interstratified illite-smectite-palygorskite. The latter could originate the formation of palygorskite (34). Towards the lowlands, palygorskite is present in small amounts, whereas montmorillonite increases substantially. This indicates that this mineral has probably formed through neoformation of Mg and Si-rich soil solutions in the lowland units (13, 25).

CONCLUSIONS

Despite the semi-arid climatic condition in southern Iran, various clay minerals occur in the soils of different physiographic units. Some inherited illite and chlorite clay minerals seem to have pedogenically transformed to montmorillonite. Neoformation of montmorillonite and palygorskite were probably from neoformation of Mg- and Si-rich soil solutions. Different proportions of similar clay minerals were found in various physiographic units. Thus, it could be concluded that pedogeomorphologic variations in water retention and transmission, reflected from catenary hydrological conditions, are responsible for changes in soil properties in semi-arid regions.

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