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SOIL GENESIS AND MINERALOGY OF THREE SELECTED REGIONS IN FARS, BUSHEHR AND KHUZESTAN PROVINCES OF IRAN, FORMED UNDER HIGHLY CALCAREOUS CONDITIONS

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ABSTRACT

Soil genesis and classification studies were carried out in three selected regions of Fars, Bushehr, and Khuzestan provinces, in southern Iran. Carbonate evolution was the main pedogenic process, however, the degree of calcic horizon development was different in various regions. In spite of ustic moisture regime in soils of Kheir Abad plain, in Khuzestan province, which have mainly originated from recent deposits, profile development is limited only to the formation of cambic horizon and thin calcic horizon. On the other hand, soils of Darab plain in Fars province, with aridic border to ustic moisture regime, show the most developed calcic and cambic horizons and also mollic epipedon. Profile development in Darab plain is probably due to greater landscape stability and also presence of groundwater and denser vegetative covers. Soils of Dashte Palang region in Bushehr province with aridic moisture regime, and scarce vegetative covers, show the intermediate stages of calcic horizon formation. Mineralogical analysis indicated little difference in type of clay minerals between different areas and different members of toposequence. However, the amount of clay minerals are different due to weathering condition, which is affected by internal drainage. Transformation processes could be the origin for the formation of smectite and palygorskite clay minerals in Dashte Palang and Kheir Abad, while in Darab plain due to more favorable drainage conditions, neoformation seems to be dominant.

Keywords: Carbonate evolution, Clay minerals, Ground water fluctuations, Soil genesis, Toposequence.

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1. Fromer Graduate Student and Associate Professor, respectively.

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مطالعه تشکیل و تکامل و کانی شناسی خاک در سه منطقه مختلف در استان های فارس، بوشهر و خوزستان در شرایط کاملا" آهکی

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چکیده

مطالعه تشکیل و تکامل خاک درسه منطقه انتخابی دراستان های فارس، بوشهر و خوزستان درجنوب ایران انجام شد. دراین مناطق مهمترین فرآیندهای خاکسازی، تغییر و تحول کربنات است اما درجه تکامل افق های کلسیک در این مناطق متفاوت است. در دشت خیرآباد (واقع دراستان خوزستان) با وجود بارندگی بیشتر و رژیم رطوبتی یوستیک به دلیل این که از رسوبات اخیر و جوان تشکیل شده ، تکامل پروفیلی فقط محدود به تشکیل افق کمبیک بوده و افق کلسیک در مراحل اولیه تشکیل و تکامل است، درحالی که در دشت داراب (واقع در استان فارس) که دارای رژیم رطوبتی اریدیک یوستیک است به دلیل تاثیر توأم پستی و بلندی، آب زیرزمینی، پوشش گیاهی فراوان و نیز ثبات اراضی، افق های کلسیک، کمبیک و نیز مالیک با درجه تکامل بسیار زیاد مشاهده شدند. دردشت پلنگ (واقع دراستان بوشهر) که دارای رژیم رطوبتی اریدیک بوده و پوشش گیاهی کمتری دارد تکامل افق کلسیک درمراحل حد واسطه است. مطالعه کانی شناسی نشان داد که نوع کانی های هرسه منطقه تقریبا" همانند ولی مقدار آن ها، در شرایط زهکشی و پستی و بلندی مختلف، متفاوت بود. منشاء اصلی کانی های اسمکتیت و پالی گورسکیت دردشت پلنگ و خیرآباد تغییر و تبدیل دیگر کانی ها به ویژه ایلیت و کلریت به این دو کانی است ولی به نظر می رسد که دردشت داراب به علت شرایط زهکشی بهتر و فراهم بودن آب زیر زمینی، عامل عمده تشکیل این دو کانی، تشکیل مجدد آن ها از محلول خاک می باشد.

INTRODUCTION

Climatic variation, carbonate evolution and ground water fluctuation are the main factors responsible for genesis and classification of soils of the studied areas. Climates vary from ustic moisture regime in soils of Kheir Abad plain, in Khuzestan province; aridic border to ustic moisture regime in soils of Darab plain, in Fars province and to aridic moisture regime in soils of Dashte Palang region, in Bushehr province.

Many processes have been proposed by numerous workers as a pathway for formation of calcic horizon (5, 24, 29, 38). Most of them are based on translocation of carbonates from near-surface horizons with reprecipitation and accumulation occuring in the zone of effective water penetrations. Landscape stability and presence of groundwater and denser vegetation covers show favorable conditions for more soil development.

Three different areas were selected for soil genesis studies:

1. Darab plain: Darab plain, with an area of 26500 ha, is one of the major agricultural regions in Fars province (Figs. 1 and 2). In this area, six different physiographic units were distinguished: alluvial-colluvial fans, plateaus, piedmont alluvial plains, alluvial plains, flood plains, and lowlands. Variation of groundwater depth has had a significant effect on soil formation and development. The climate of the area is characterized by hot and dry summers. The mean annual rainfall is about 257mm, and mean annual air temperature is 21.5°C. The soil moisture and temperature regimes are aridic border to ustic and hyperthermic, respectively (32).

2. Dashte Palang plain. Dashte Palang intermountain plain with an area of 6650 ha, is in Bushehr province (Figs. 1 and 3). This area has been subdivided into three physiographic units: piedmont plateau, upper terraces and plateaus and river terraces. Dashte Palang river is a permanent source of water for agriculture. Ground water is very deep, and has had no effect on soil genesis. The climate of the area is considered warm desertic. The average annual rainfall and temperature are 210 mm and 24.6 °C, respectively. The soil moisture and temperature regimes of the area are aridic and hyperthermic, respectively (32).

3. Dashte Kheir Abad plain. This plain with an area of 2100 ha is in Khuzestan province (Figs. 1 and 4). The area consists of three physiographic units: terraces, piedmont alluvial plains, and gravely river alluvial fans. Kheir Abad River flows along the study area and is the major water resource for agriculture. The average annual rainfall and temperature are 320 mm and 21.5 °C,

respectively. The soil moisture and temperature regimes are ustic and hyperthermic, respectively (32).

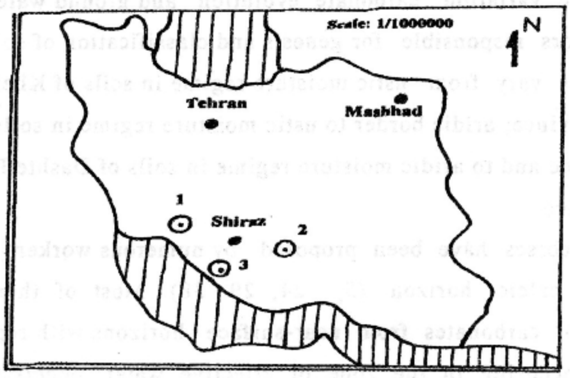

Fig. 1. Location map of three studied regions.
1. Kheir Abad plain, 2. Darab plain, 3. Dashte Palang plain.

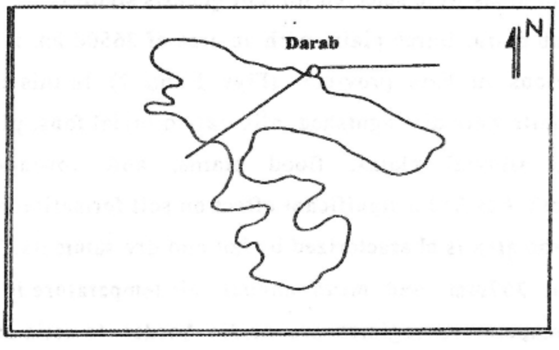

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Fig. 2. Location map of Darab plain.

Study of soil genesis over these areas could be helpful for finding a relationship between climate and soil development in highly calcareous parent materials. The main objectives of these investigations were: 1- to study the fundamental principles of soil formation under different climates, physiographic units, and drainage conditions, and 2- to study the clay transformation and neoformation due to the effect of topography, ground water, and climatic factors.

MATERIALS AND METHODS

Field Work

In each of the three study areas, selection of the site of soil profiles for pedogenic studies was based on aerial photo-interpretations, followed by field investigations. Various physiographic units of the areas were analyzed and classified according to land use, land type, hydrological network, relief form, color tone and vegetation.

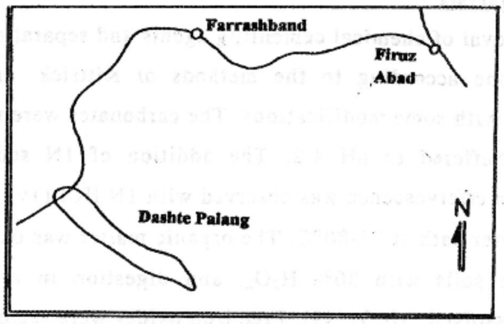

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Fig. 3. Location map of Dashte Palang.

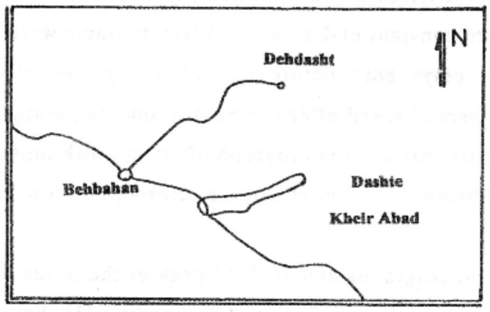

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Fig. 4. Location map of Dashte Kheir Abad.

The soils are described and classified according to USDA soil survey manual (33), Keys to Soil Taxonomy (34) and FAO system (14), respectively.

Physico-chemical Analysis

Particle-size distribution was determined after the dissolution of $CaCO_3$ with 2N HCl, and decomposition of organic matter with 30% H_2O_2. After repeated washing for removal of salts, the soils were dispersed by using sodium hexametaphosphate. The sand, silt and clay fraction were separated by sedimentation and determined by the pipette method (13). Alkaline-earth carbonate (lime), was measured by acid neutralization (37). Organic carbon was measured by wet oxidation with chromic acid and back titered with ammonium ferrous sulfate (19). Gypsum ($CaSO_4.2H_2O$) was determined by precipitation with acetone (37). pH was measured in saturation paste and also in groundwater by a Beckman pHmeter. Electrical conductivity was determined in the saturation extract. Cation Exchange Capacity (CEC) was determined by NaOAC at pH 8.2 for soil and clay particles (11).

Mineralogical Analysis

The removal of chemical cementing agents and separation of the different fractions were done according to the methods of Kittrick and Hope (22), and Jackson (19), but with some modifications. The carbonates were removed using 1N sodium acetate buffered to pH 4.2. The addition of 1N sodium acetate was continued until no effervescence was observed with 1N HCl (19). The reaction was performed in a water bath at 75-80°C. The organic matter was oxidized by treating the carbonate-free soils with 30% H_2O_2, and digestion in a water bath. This treatment also dissolved MnO_2 (19). Free iron oxides were removed from samples by citrate dithionate method (26). The iron-free samples were centrifuged at 750 RPM for 5.4 min and clay separates removed and were studied with X-ray diffraction using Ni filtered CuKa radiation (40 kV and 40 mA), a range factor of 400 CPS and a time constant of 1 s. X-ray diffractograms were obtained from Mg-saturated samples clays both before and after glycerol solvation. Potassium-saturated samples were X-rayed after drying at room temperature and after heating at 550° C for 2 hours. Electron micrograph of citrate-dithionite treated clays were obtained with a Philips SM 300 electron microscope following the techniques of Bates (6).

The electron micrographs and 10.5 A° peak of the X-ray diffractograms were used for semi-quantitative determination of palgorskite (1). Four randomly selected 35,000 X photographs (8 by 8 cm) were used with a transparent 5-mm grid to estimate the palygorskite content of each sample by point counting. Since no feldspars were observed in the clay fraction, the percentage of illite were estimated from the total K_2O content of the clay (19).

Vermiculite in the clay fraction was determined quantitatively by the method of Alexiades and Jackson (4). Quantification of other minerals such as smectite, chlorite and quartz were estimated from their relative peak intensities using the glycerol treated samples (20).

RESULTS AND DISCUSSION

A. Pedological Evolution of Darab Plain

The two main factors responsible for the evolution of soils of Darab plain are: carbonate evolution and ground water fluctuations, which are largely dependent on the physiographic position of the soils.

Soils of alluvial-colluvial fans. Profiles on this physiographic unit(i.e. Sheikhi series, Tables 1 and 2), lack any diagnostic horizons other than an ochric epipedon. Carbonates are mostly present as limestone fragments. This first stage of pedogenic evolution has also been reported by Abtahi (2). Lack of any diagnostic horizon, is due to unstable soil surface resulting from periodic addition of fan sediments which further reduces the time available for pedological evolution.

Soils of piedmont alluvial plains. The somewhat more developed soils on the piedmont slopes have cambic horizons (Galugah series, Tables 1 and 2), produced by redistribution of carbonates. In the finer textured soils (Miandeh series), redistribution of carbonates is manifested by the presence of fine secondary calcite crystals, and carbonate nodules (Table 2). The observation presented by Pennock and Vreeken (28) allow the discussion of several pedological processes responsible for the formation of cambic horizon. Calcium carbonates occur as of nodules and soft powdery pockets in subsurface horizons, which indicate their translocation during rainy season and precipitation during hot dry summers. These secondary calcium carbonates occur in amounts too small to meet the requirements of a calcic horizon. The redistribution of carbonates in these profiles is difficult to recognize from laboratory calcium carbonate determinations, which do not distinguish between primary and secondary calcite (Table 2); however, carbonate differentiation is quite clear from field morphology (Table 1). It is also important to note that loss of carbonate from the surface horizons may be compensated by a continuous recharge of $CaCO_3$ from sediment deposition from topographically higher limestone outcrops (1, 2, 3). A number of processes have been proposed to explain calcic horizon formation, ranging from simple solution, translocation, and reprecipitation (5, 29), recrystallization of limestone (38), and capillary rise (24), to more complex lateral landscape redistribution mechanisms(17, 31). Most of the proposed pathways for formation of calcic horizons are based on translocation of carbonates from near-surface horizons with reprecipitation and accumulation occurring in the zone of effective water penetration (9). In the soils of piedmont plains in Darab plain (Miandeh series), this process seems to be less effective, because if this pathway is dominant, reconstruction of carbonate gains and losses would be expected to show carbonate losses from horizons above calcic horizon, and the calcic horizon would be expected to show a considerable gain of carbonates (Table 2). Tables 1 and 2 indicate that with almost the same amount of calcium carbonate in all horizons of Miandeh soil series, there is significant differences in the amount of secondary calcium carbonates among different horizons. Therefore, we suggest that *in situ* recrystallization of the limestone was the main process

Table 1. Morphology and classification of soils in the three study regions.

Horizon	Depth (cm)	Color (moist)	Structure	Consistence† (moist)	Boundary	Other components+
		Darab plain, Sheikhi series (Aridic Ustorthents) Alluvial-colluvial fans				
A1	0-20	10YR 3/2	-	fr	cs	few fine roots
C1	20-50	10YR 5/4	-	fr	cs	-
C2	50-80	10YR 5/4	-	fr	cs	-
C3	80-150	10YR 5/4	-	fr	-	-
		Darab plain, Galugah series (Aridic Haplustepts) Piedmont alluvial plains				
Ap	0-25	10YR 4/3	clsabk	fr	cs	few to common fine roots
Bw1	25-65	10YR 4/4	clabk±(mlabk)	fr	gs	few fine roots
Bw2	65-135	10YR 4/4	clabk±(m2abk)	fr	-	-
		Darab plain, Miandeh series (Aridic Calciustepts) Piedmont alluvial plains				
Ap	0-30	10YR 4/4	clsabk	fi	cs	few to common fine roots
Bk1	30-65	10YR 4/4	m2sabk	vfi	gs	few lime powdery pockets and concretions
Bk2	65-135	10YR 4/4	mlabk±(m2abk)	vfi	-	few lime powdery pockets and concretions
		Darab plain, Pole-Bahadoran series (Typic Calciaquolls) Lower alluvia plains				
Apg	0-23	10YR 3/2	m2gr±(flabk)	fi	cs	few to common fine roots
Bkg1	23-65	10YR 5/2	m±(clabk)	fi	cs	common fine irregular lime powdery pockers, few to common fine toots, common snail shells
Bkg2	65-100	10YR 4/2	m±(mlabk)	fi	gs	many fine irregular lime powderly pockets and concretions, common snail shells
Bkg3	100-140	10YR 4/2	m±(mlabk)	fi	-	few fine lime powdery pockets, few fine faint dark grayish brown (2.5YR 4/2) mottles, common snail shells
		Darab plain, Dehnow seies (Fluvaquentic Endoaquolls) Lowlands				
Apg	0-23	10YR 3/1	m3gr	fi	gs	many fine roots
Bkg1	23-65	10YR 3/2	m2ab±(gr)	fi	cs	few fine faint mottles, many fine roots
Bkg2	65-100	10YR 4/2	m2abk	fi	cs	few fine faint mottles, few snail shells common
Bkg3	100-140	10YR 6/1	m2abk	fi	-	common medium sistinct yellowish brown (10YR 5/6) mottles, few fine lime powdery pockets, few fine roots
		Dashte Palang plain, Abkhosh series (Typic Haplocalcids) River terraces				
Ap	0-15	10YR 4.5/4	-	fi	cs	many fine roots
Bw	15-40	10YR 4.5/4	clabk±(m2abk)	fi	cs	many fine roots,>5% gravel
Bk	40-80	10YR 5/4	clabk±(m3abk)	fi	cs	Few lime powdery pockets and concretions
C	80-150	10YR 5/4	mlsabk	fi	-	few fine roots
		Dashte Kheir Abad plain, Dehveh series (Typic Haplustepts) Piedmont alluvial plain				
Ap	0-30	10YR 5/2	-	fi	cs	few fine roots
Bw	30-90	10YR 6/4	mlabk	fi	cs	-
C	90-130	10YR 6/3	-	fi	-	-

†. Symbols used according to abbreviation given is Soils Survey Manual, USDA Handbook No. 18, pp. 139-140, 195.
+. All soils are calcareous throughout.
±. Indicates primary structure that parts to secondary structure when ruptured.

Table 2. Selected physico-chemical properties of pedons in the three study regions.

Horizon	Depth	Particle Size Distribution				Textural	pH	OC†	CCE§	SP¶	Gypsum	CEC††	EC§§
		Sand	Silt	Clay	Gravel	class	paste						
	cm	----------	%	----------				----------	%	----------		cmol kg^{-1}	dS m^{-1}
					Darab plain, Sheikhi series								
A1	0-20	49.0	38.0	13.0	25.0	l	7.6	0.1	35.0	32.6	0.2	8.8	0.4
C1	20-50	59.0	28.0	13.0	55.0	sl	7.7	tr¶¶	37.0	36.3	tr.	7.8	0.4
C2	50-80	57.0	29.0	14.0	70.0	sl	7.4	tr.	42.5	43.6	tr.	8.7	0.5
C3	80-150	66.0	21.0	13.0	75.0	sl	7.6	tr.	49.4	37.8	tr.	8.0	0.3
					Darab plain, Galugah series								
Ap	0-25	12.6	53.7	33.7	-	sicl	7.4	0.5	43.4	57.6	0.3	14.5	2.8
Bw1	25-65	23.2	48.0	28.8	-	cl	7.8	0.3	44.2	53.6	0.2	14.3	3.7
Bw2	65-135	22.6	47.8	29.6	-	cl	7.5	0.1	43.1	52.1	0.3	13.2	2.3
					Darab plain, Miandeh series								
Ap	0-30	12.7	49.6	37.7	-	sicl	7.5	1.1	41.2	55.5	0.4	15.5	5.4
Bk1	30-65	10.6	48.1	41.3	-	sic	8.1	0.7	42.4	61.6	0.2	15.0	2.3
Bk2	65-135	10.5	49.2	40.3	-	sic	8.2	0.2	43.6	60.2	0.2	13.2	3.2
					Darab plain, Pole Bahadoran series								
Apg	0-23	24.6	45.7	29.7	-	cl	7.5	2.8	45.6	63.5	0.3	19.8	2.3
Bkg1	23-65	36.6	37.7	25.7	-	l	7.8	1.0	58.1	57.5	0.2	14.7	2.4
Bkg2	65-100	34.6	41.7	23.7	-	l	8.1	1.2	68.7	63.5	0.2	13.9	3.1
Bkg3	100-140	30.6	42.7	26.7	-	l	7.8	0.9	62.5	59.8	0.2	15.0	3.2
					Darab plain, Dehnow series								
Apg	0-25	23.0	35.5	41.5	-	c	8.1	4.9	38.8	60.8	0.2	30.4	3.4
Bg1	25-50	15.2	32.0	52.8	-	c	8.2	1.8	39.2	52.7	0.1	29.0	1.4
Bg2	50-90	23.2	34.0	42.8	-	c	1.2	1.2	41.3	50.1	0.3	23.0	1.1
Bg3	90-140	31.2	37.0	31.8	-	cl	0.8	0.8	41.5	41.5	0.2	16.8	0.7
					Dashte Palang plain, Abkhosh series								
Ap	0-15	33.4	38.0	28.6	-	cl	7.4	0.4	12.5	47.9	tr.	11.0	1.5
Bw	15-40	35.4	34.0	30.6	-	cl	7.3	0.2	28.7	46.8	tr.	10.0	1.2
Bk	40-80	29.4	43.0	27.6	-	cl	7.2	0.1	40.0	45.8	tr.	10.0	1.2
C	80-150	35.5	46.0	18.5	-	l	7.6	0.1	75.0	43.3	tr.	9.5	0.7
					Dashte Kheir Abad plain, Dehveh series								
Ap	0-30	21.4	42.0	36.6	-	cl	7.4	0.6	25.0	42.0	0.7	12.0	0.9
Bw	30-90	17.4	42.0	40.6	-	sicl-sic	7.4	0.2	25.0	43.8	0.5	11.1	0.9
C	90-130	26.4	37.0	36.6	-	cl	7.4	0.1	27.5	46.0	0.8	11.0	0.7

† OC=Organic carbon, § CCE=Calcium carbonate equivalent, ¶ SP=Saturation percentage, †† CEC=Cation exchange capacity, §§ EC=Electrical conductivity ¶¶ tr=trace

involved in the formation of pedogenic carbonates. This hypothesis is in agreement with the findings of West *et al.* (38) and the commonly accepted model (translocation and reprecipitation) does not solely apply to these soils.

Soils of alluvial plains and lowlands. Development of profiles on older alluvial plains and lowlands, largely depend on calcium carbonate and organic matter distribution which are affected by groundwater fluctuations (7, 8, 35, 36). On upper parts of alluvial plains with water table depth of about two meters (in summer), soils show calcic horizon in addition to mollic epipedon and gleying evidences (Pole Bahadoran series, Table 1). During the field study it was noted that the degree of $CaCO_3$ redistribution and accumulation differ greatly among soils of the study areas. Formation of calcic horizon in soils with shallow groundwater (Pole-Bahadoran) is related mainly to discharge from shallow water table, which precipitated as secondary carbonates in the sola due to evapotranspiration and precipitation from upper horizons during dry period (24). The formation of secondary calcium carbonate in soils with deeper groundwater is due to dissolution of carbonate, their migration to lower horizon, during cold rainy winter and their precipitation during hot dry summer (1, 2). Many scientists have studied the formation of clacic horizons in condition similar to this study area (21, 23). They relate the secondary carbonates present in these soils to discharges from a shallow water table. This shallow water table contributed to higher concentration of soluble calcium bicarbonate and precipitated as secondary carbonates in the sola, on lower landscape positions due to evapotranspiration and desiccation. Therefore, the main cause for the presence of a highly developed calcic horizon in Pole Bahadoran series, is the occurrence of a shallow groundwater. Also translocation of carbonates from upper horizons during rainy seasons and its subsequent precipitation during hot dry summers can be the other cause for the formation of calcic horizon. Since climate of study area is hot desertic (annual rainfall of 257 mm), the latter case seems to be less effective.

Soil formed in lower alluvial plain (i.e. lowlands, Dehnow series, Tables 1, 2), show no calcic horizon but large accumulation of organic carbon and strong gleying. Almost permanent saturation condition in the lower horizons has prevented the carbonates to precipitate in the form of secondary patterns (i.e. powdery pockets, concretions, etc.). Considering above statements, soils of Darab plain show different stages of development which are affected mainly by topography and depth of water as follows:

1. Foothill soils (Sheikhi series) with no diagnostic horizons are in the very early stages of development.

2. **Soils of piedmont plains (Galugah and Miandeh series) showing cambic and calcic horizons.**
3. **Soils of alluvial plains, with shallow groundwater table (Pole Bahadoran series) showing developed calcic horizon and mollic epipedon.**
4. **Soils of lowlands with shallow water table showed no calcic horizon but developed mollic epipedon.**

Three processes were responsible in the formation of pedogenic carbonates in Darab plain:

1. **Translocation of carbonate and its subsequent precipitation in lower horizons(as in Miandeh and Pole Bahadoran series).**
2. **Recrystallization of lime(dominant process in Miandeh series).**
3. **Capillary rise due to water table (dominant process in Pole Bahadoran series).**

B. Pedological Evolution of Dashte Palang and Dashte Kheir Abad Plains

In both study areas, topography is the most important factor affecting soil formation. Soils with no calcium carbonate redistribution are situated on mountainous areas and alluvial-colluvial fans. These are young soils of Holocene age, and show no evidence of secondary carbonate accumulation. This trend is the same as that discussed earlier for Darab plain. The soils which are formed on gently sloping piedmont plains (Dehveh series, Tables 1, 2, Dashte Kheir Abad), are less developed soils and indicate a cambic horizon in the form of structural development and carbonate redistribution. Development of soils of Kheir Abad plain, has been limited to this stage, but more soil development occurred on flat piedmont plains and plateaus in Dashte Palang (Abkhosh series, Tables 1 and 2). The soil profile shows a calcic horizon with many secondary carbonates in the forms of nodules and soft powdery pockets. The formation of secondary calcium carbonates in soils of Dashte Palang with aridic moisture regime is due to dissolution of carbonates, their migration to lower horizons, during cold rainy winter and their precipitation during hot dry summer (2). In conclusion, presence of the more developed calcic horizons in Dashte Palang with aridic moisture regime is largely due to more landscape stability, which has provided more time for soil formation and development. However, in Dashte Kheir Abad, with ustic moisture regime, soils are almost less developed, and show early stages of calcic horizon formation. This is due to the periodic deposition of fan and river materials which reduce the time available for soil formation.

C. Mineralogical Study of Clay Fraction in Three Study Regions

Mineralogical study of soils in three regions revealed that the minerals were more or less similar in type but different in the relative occurrence. This difference could be attributed to the change in drainage conditions resulting from variation in topography (12). X-ray diffractograms, show the presence of illite, smectite, chlorite, palygorskite, quartz, with traces of vermiculite and regularly interstratified system of expandable layer silicates with illite and chlorite (Fig. 5, and Table 3). Fig. 6 shows presence of fibrous clay mostly palygorskite in soils.

According to Henderson and Robertson (15), and Martin Vivaldi and Robertson (25), the limestone of southern Iran contains only minor amounts of palygorskite and smectite. It has also been stated that the same parent rocks include equal amounts of illite, chlorite and quartz (10). Therefore, it may be concluded that the presence of large quantity of palygorskite or smectite in soils could be due to pedogenic processes (16, 18, 27, 30).

Amount of smectite and palygorskite in soils of the study areas has a strong relationship with drainage and calcium carbonate content. Under poor drainage conditions, smectite mineral was dominant in clay minerals (Pole Bahadoran series). Darab plain, Table 3 and Fig. 3). As shown in Table (3), in Abkhosh and Miandeh series, palygorskite content increased under well-drained conditions as calcic horizon formed in these soils. In Dehveh series (Dashte Kheir Abad plain), however, due to early stages of development of calcic horizon, chlorite is dominant. According to Abtahi (1, 2) transformation and neoformation are the two major mechanisms responsible for the formation of palygorskite and montmorillonite in soils of arid regions of Iran. The transformed origin is proposed for the formation of these two clay minerals in Dashte Palang and Kheir Abad plains, however in Darab plain due to the more favorable drainage conditions, neoformation of these two minerals from soil solution seems to be dominant.

Table 3. Semi-quantitative analysis of the soil clay in three studied areas†.

Location	Soil Series	Depth (cm)	Palygorskite	Smectite	Illite	Chlorite	Vermiculite	Quartz
Darab	Sheikhi	50-80	+	N	+++	++	N	+
Darab	Galugah	25-65	+++	+	++	+	+	+
Darab	Miandeh	65-135	+++	+	++	++	N	+
Darab	Pole Bahadoran	65-100	+	++++	++	++	+	+
Darab	Dehnow	50=90	+	++	++	+++	N	+
Dashte palang	Abkhosh	40-80	++++	+	++	+++	N	+
Dashte Kheir Abad	Dehveh	30-90	+	++	+	+++	+	+

†. ++++=50-75%, +++=25-50%, ++=10-25%, +=<10%, and N=not detected

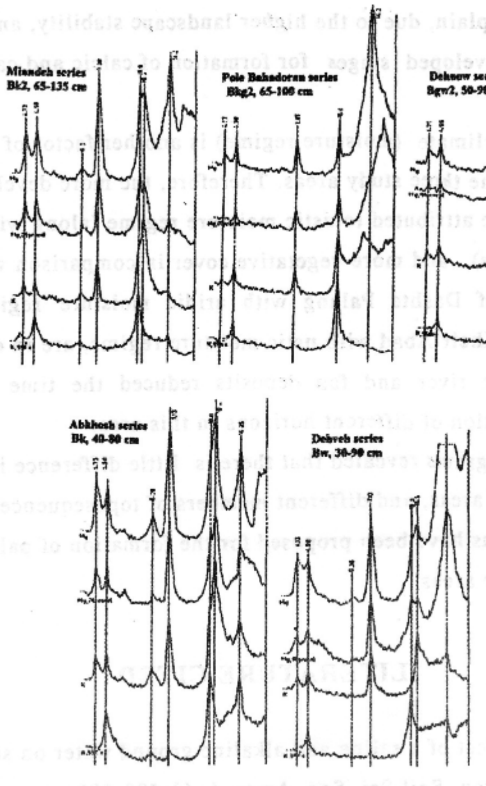

Fig. 5. X-ray diffraction patterns of clay in three study regions.

Fig. 6. Electron micrograph of fibrous palygorskite clay from the sub-surface horizon of Pole Bahadoran series, Darab plain.

CONCLUSIONS

Based on the findings of this stady it can be concluded:

1. In the three study areas, pedogenic processes are largely attributed to carbonate evolution, however the degree of calcic horizon development, and processes involved in its formation are different.

2. Soils of Darab plain, due to the higher landscape stability, and groundwater effects, show well developed stages for formation of calcic and cambic horizons and mollic epipedon.

3. Influence of climate (moisture regime) is another factor of soil formation which is different in the three study areas. Therefore, the more developed horizons of Darab area may be attributed to ustic moisture regime (along with surface and subsurface water flows), and more vegetative cover in comparison with somewhat less developed soils of Dashte Palang with aridic moisture regime and scarce vegetation. Soils of Kheir Abad with ustic moisture regime, are in early stages of development. Periodic river and fan deposits reduced the time available for development and formation of different horizons in this area.

4. X-ray diffractograms revealed that there is little difference in type of clay minerals between three areas, and different members of toposequence in each area, however different origins have been proposed for the formation of palygorskite and montmorillonite in three areas.

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