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SOIL GENESIS AS AFFECTED BY TOPOGRAPHY AND DEPTH OF SALINE AND SODIC GROUND WATER UNDER SEMIARID CONDITIONS OF IRAN

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ABSTRACT

Soils of the Maharlu, Kamal-Abad, Sayf-Abad and Chartaghi soil series, all calcareous developed in the Sarvestan intermontane basin under similar climatic and parent material conditions but with different topography and depth to saline and sodic ground water, were investigated. Marked differences in the morphological, physical, chemical and mineralogical properties of the four soils were associated with variation in topography and the depth of saline and sodic ground water. Soils with salic horizons (Aquollic Salorthids) have been formed on the lowlands with shallow ground water, soils with gypsic horizons (Salic Gypsiorthids) on alluvial plains with moderately deep ground water, soils with natric horizons (Typic Natrixeralfs) on the lower piedmont plains with deep ground water, and soils with argillic horizons (Calcic Haploxeralfs) on the upper piedmont plains with very deep ground water. Exchangeable Na, the major cause of clay dispersion and migration, is only effective whenever the excess salts have been leached out. Salination and alkalization, desalination, solonization and dealkalization are four successive processes in the formation of these soils.

X-ray and electron optical analyses indicated that palygorskite increases with decrease of smectite towards the upper part of the intermontane basin.

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تاثیر پستی و بلندی و عمق سفره آب زیرزمینی شور و قلیا در تشکیل خاک درتحت شرایط نیمه‌خشک ایران

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چکیده

خاکهای سری مهارلو، کمال آباد، سیف آباد و چهار طاقی تماما آهکی تشکیل شده در حوضه سروستان درتحت شرایط آب و هوایی و مواد مادری مشابه ولی پستی و بلندی و عمق سفره آب زیرزمینی شور و قلیا مختلف مورد مطالعه قرار گرفت. اختلافات عمده در مورفولوژی، خواص فیزیکی، شیمیایی و مینرالوژیکی چهار سری خاک بستگی کامل به تغییرات پستی و بلندی و عمق سفره آب زیرزمینی شور و قلیا دارد.

خاکهای با افق سالیک (اکوالیک سال اورتید) در اراضی پست با سفره آب زیرزمینی کم‌عمق، خاکهای با افق جیپسیک (جیپسیک زرواکرپت) در دشت‌های رسوبی با سفره آب زیرزمینی نسبتا عمیق، خاکهای با افق ناتریک (تیپیک ناتری زرالف) در دشت‌های دامنه‌ای پایین با سفره آب زیرزمینی عمیق و خاکهای با افق آرجیلیک (کلسیک هاپل زرالف) در دشت‌های دامنه‌ای بالائی با سفره آب زیرزمینی خیلی عمیق تشکیل شده‌اند. سدیم قابل تبادل بعنوان عامل اصلی در پراکندگی و انتقال رس وقتی موثر است که نمکهای اضافی از خاک خارج شوند. شور و قلیا شدن، شوره‌زدائی، پیدا شدن حالت سولونتزی و قلیازدائی چهار مرحله متوالی در تشکیل خاک بحساب می‌آیند. آزمایشات اشعه ایکس و میکروسکوپ الکترونی نشان داد که درنقاط مرتفع‌تر حوضه با افزایش رس پالی گورسکیت رس اسمکتیک کاهش می‌یابد.

INTRODUCTION

The Sarvestan basin, which is a typical intermontane basin, lies in southern Iran, about 50 km east of Shiraz (Fig. 1). This basin is 80 to 90 km long in a northwest to southeast direction, and 10 to 15 km wide in a north to south direction. The altitude of the basin varies from 1,400 m above mean sea level near the lake surface to 1,800 m above mean sea level at the foot of the mountains. The climate is Mediterranean with an average annual precipitation of 332 mm. The highest and lowest mean monthly temperatures (1950-1974) are 28.4 and 6.2°C for July and January, respectively. Most of the soils, therefore have a xeric moisture regime and the soil temperature can be classified as thermic (7).

Fig. 1. Location of study area in Iran.

The Sarvestan basin (Fig. 2) is formed by tectonic movements of the Zagros mountain ranges during Mio-Pliocene time (21). During the Quaternary period, thick lacustrine materials were deposited in the central part of the basin. The area surrounding the lake is composed of alluvial-colluvial deposits. Towards the lake these become thinner and are replaced by lacustrine deposits. As a result of these depositional patterns, several physiographic units may be defined on the basis of salinity status: lowlands and alluvial plains with severe to very severe salinity influenced by lacustrine conditions (No. 3 on Fig. 2), piedmont plains having a uniform fine texture with slight salinity, influenced by semilacustrine conditions (No. 2 on Fig. 2); alluvial fans, alluvial-colluvial fans, upper terraces and fan erosional remnants with no salinity problem at the outer margin (No. 1 on Fig. 2).

The native vegetation of the area consists of many species and their distribution follows a zonation controlled by topography and depth of ground water. The most important plant associations are: a) on shallow non-saline soils and fans, the association of *Artemisia* sp.,

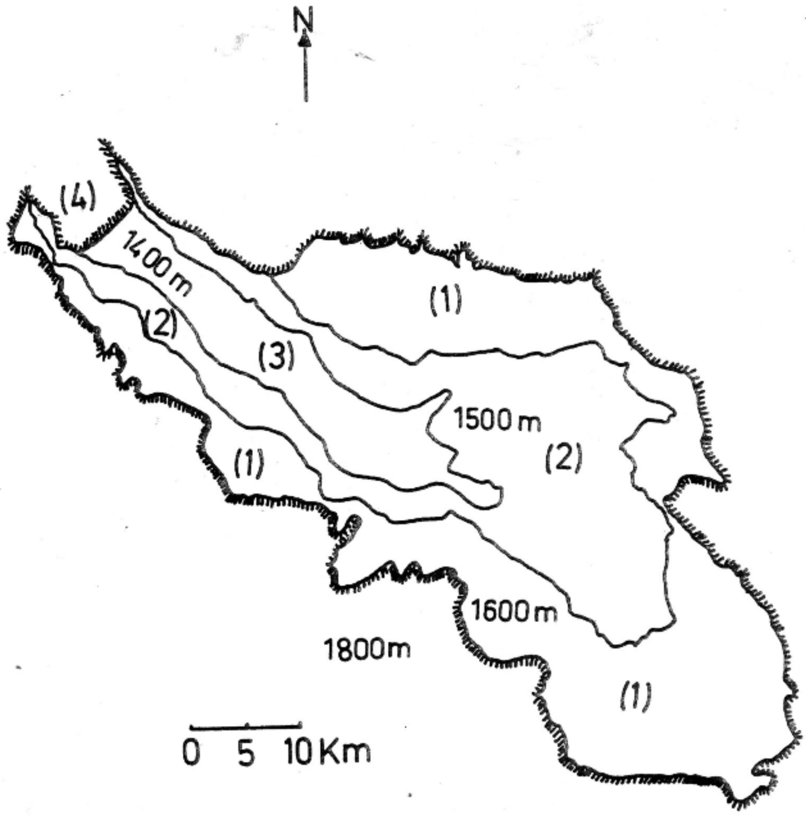

Fig. 2. Soil salinity and landform relationships in Sarvestan basin. (Abtahi, 1978).

(1) Land with no salinity problem (alluvial-colluvial fans, alluvial fans, upper terraces, and fan erosional remnants).
(2) Land with slight to moderate salinity problem (piedmont plains).
(3) Land with severe to very severe salinity problem (alluvial plain and lowland).
(4) Salt lake.

Zygophyllum atriplicoides, *Peganum harmala* and some *Gramineae*; and b) in very saline alluvial plains, the association of *Salsola* sp., *Salicornia herbacea*, *Suaeda* sp. and *Tamarix* sp. In extremely saline lowlands where water tables are near or almost at the surface, even highly tolerant halophytes cannot grow.

The parent materials of soils are variably textured and highly calcareous, being derived from surrounding limestone mountains.

Two evolutionary sequences of soil formation are proposed for this synclinal basin: one with respect to topography and time (topochronosequence) with none to moderate salinity problems under well-drained conditions on the flanks of the basin, and another with severe to very severe salinity problems under the influence of saline ground water at various depths in the central part of the basin. In this paper, attention was directed mainly to soil formation as affected by topography and depth of saline and sodic ground water of the central part of the basin. The evolution of salt-affected soils have been studied by several workers (1, 5, 13, 14, 23, 25, 26). Soil formation under the well-drained conditions of the surrounding of the basin has been discussed in another paper (3).

MATERIALS AND METHODS

The soils were described and classified according to the USDA, Soil Survey Manual (35) and Soil Taxonomy (36), respectively (Table 1).

Samples of water for quality determination were collected during the end of spring either directly from each study site or from surrounding wells.

Particle-size analysis of soil samples was determined by the hydrometer method after gypsum and other soluble salts were removed from samples

Table 1. Some morphological characteristics and classification of the soils studied.

Horizon	Depth,cm	Munsell color (moist)	Texture[†]	Structure[†]	Consistence[†]	Boundary	Other components[‡]
STAGE 1: SALINATION AND ALKALIZATION							
		Lowland,Maharlu series(Aquollic Salorthids)					
C1sa	0-10	2.5Y5/3	cl	f1gr	mfr	c	Very saline
C2sa	10-55	2.5Y5/3	cl	f1sbk	mfr	c	Very saline;m1d mottles of 5Y6/3 and 2.5Y5/6
C3sa	55-70	10Y5/3	c	f1sbk	mfr	c	Very saline;m3p mottles of 2.5Y5/3
C4sa	70-100	5Y5/2	cl	m	mfr	-	Very saline
STAGE II: DESALINATION							
		Alluvial plain,Kamal-Abad series(Salic Gypsiorthids)					
A1	0-20	7.5YR4/4	sicl	f2gr	mfr	cs	Very few fine roots
C1cs	20-55	7.5YR4/4	scl-l	c3abk	mfi	gs	Gypsiferous;saline,common gypsum crystals
C2cs	55-90	7.5YR4/4	cl	m2abk	mfi	gs	Gypsiferous;saline,common gypsum crystals
C3sa	90-140	7.5YR5/4	sil	m1sbk	mfi	gs	Very saline; few gypsum mycelia
C4sa	>140	7.5YR5/4	cl	m	mfi	-	Very saline
STAGE III: SOLONIZATION							
		Lower piedmont plain,Sayf-Abad series(Typic Natrixeralfs)					
A2	0-16	10YR5/4	sic	f2sbk	mfr	cs	Common fine roots
B21t	16-36	10YR4/4	c	m3prim2cpr[§]	mfi	gw	Few roots;few broken thin clay skins on the ped faces
B22t	36-70	5Y5/3	c	m3pric3abk[§]	mfi	gw	Continuous,thin clay skins on the ped faces
B3t	70-90	5Y5/3	c	m3abk	mfi	cs	Broken,thin clay skins on the ped faces
C1cs	90-140	5Y6/2	c	m	mfi	cs	Few gypsum crystals and mycelia
C2	140	5Y5/2	c	m	mfi	-	-
STAGE IV: DEALKALIZATION							
		Upper piedmont plain, Chartaghi series(Calcic Haploxeralfs)					
A2	0-30	7.5YR4/4	cl-sicl	m2gr	mfr	cs	Common fine roots
B21t	30-45	7.5YR4/4	sic	m3abk	mfr	gs	Broken,moderately thick clay skins on the ped faces;common rounded powdery carbonate bodies
B22t	45-65	7.5YR4/3	sic	m3abk	mfr	d	Continuous,thick clay skins on the ped faces;common rounded powdery carbonate bodies
IIC	65-135	5.YR3.5/4	cl	m	mfi	-	Gypsiferous; many gypsum crystals

[†] Symbols used according to abbreviation given in Soil Survey Manual, USDA Handbook no.18, p.139-140, 1951.

[‡] All soils are calcareous throughout.

[§] Indicates primary structure that parts to secondary structure when ruptured.

by repeated washing with distilled water (10). The soil pH, EC and soluble ions were measured on saturated paste extracts (37). Gypsum and alkaline earth carbonates were also determined (37). Organic carbon in the soil was measured by wet oxidation method of Walkley and Black (19). Cation exchange capacity (CEC) was determined by 1M NaOA° (pH=8.2) for soil samples and 1M $NH_4OA°$ (pH=7) for clay fraction (12).

Water-dispersible clay was determined on untreated samples of soil and clay. To find the degree of dispersion of clay under natural conditions, the soils were dispersed in distilled water without addition of any dispersing agent. After required period of time, the amount of clay was determined and assumed to be equal to dispersed clay under natural conditions.

Removal of chemical cementing agents and separation of different size fractions for mineralogical analyses were done according to the methods of Kittrick and Hope (24) and Jackson (20), respectively. Free iron oxides were removed from clay sample by the citrate-dithionite method (30). The treated clay was dried on glass slides and examined by X-ray diffraction, by using Ni-filtered CuKa radiation, a range factor of 400 cps and a time constant of 1s. X-ray diffractograms were obtained from Mg-saturated soil 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 hr.

Electron micrographs of citrate-dithionite treated clays were obtained with a Phillips SM 300 electron microscope following the technique of Bates (8).

The electron micrographs and 10.7 A° peak of the X-ray diffractograms were used for the semi-quantitative determination of palygorskite (1). Four randomly selected 35,000X 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 (20).

Vermiculite in the clay fraction was determined quantitatively by the method of Alexiades and Jackson (6). Quantification of other minerals such as smectite, chlorite and quartz was estimated from their relative peak intensities using the glycerol treated samples (22).

RESULTS AND DISCUSSION

The two main factors influenced by topography, namely the depth of ground water and the degree of salinity of ground water, are responsible for genesis of soils of the studied area. Maharlu, Kamal-Abad, and Chartaghi soils formed an evolutionary sequence of soils developed under the influence of a saline ground water with high SAR values (Tables 1 and 2). The different members of the toposequence may be grouped according to specific processes of soil development. Four processes in the formation of these soils could be recognized.

Maharlu Soil Series

Salination and alkalization in this series have resulted in soils that can be classified as Salorthid according to Soil Survey Staff (36). Ground water is extremely saline (75 dSm^{-1}) and has a very high SAR value of 124 (Table 3). During the rainy winter due to rising of ground water, the soils are flooded with saline and sodic ground water, while during summer intensive evaporation takes place (2). The result is a high concentration of Na and other salts throughout the profile (Tables 1 and 2). The main soil forming processes are, therefore, salination and alkalization. In spite of the high ESP values for the Maharlu pedon,

Table 2. Some physical and chemical characteristics of the soils studied.

Horizon	Depth cm	EC dSm^{-1}	pH (paste)	Water dispersible clay: of soil	Water dispersible clay: of total clay	Organic matter	$CaCO_3$	Gypsum	particle-size distribution: sand	particle-size distribution: silt	particle-size distribution: clay	Texture	CEC: Soil	CEC: Clay	ESP
						%							meq $100g^{-1}$		
STAGE I: SALINATION AND ALKALIZATION															
Lowland, Maharlu series (Aquollic Salorthids)															
C1sa	0-10	112	7.7	3.0	8.8	1.5	35	5	26	40	34	cl	19.5	62.4	64
C2sa	10-55	89	7.6	3.0	7.8	1.3	35	10	34	28	38	cl	24.0	66.4	58
C3sa	55-70	105	7.7	2.8	5.8	1.0	39	8	22	30	48	c	19.5	57.6	57
C4sa	70-100	123	7.5	4.4	12.9	1.2	43	6	26	40	34	cl	15.0	55.6	68
STAGE II: DESALINATION															
Alluvial plain, Kamal-Abad series (Salic Gypsiorthids)															
A1	0-20	08	7.6	3.0	10.7	1.0	33	0.3	16	56	28	sicl	15.0	46.4	5
C1cs	20-55	27	8.4	6.3	26.2	0.3	23	23.0	48	28	24	scl-l	13.4	44.0	38
C2cs	55-90	44	8.5	7.4	21.9	0.2	35	10.3	26	40	34	cl	15.6	33.8	41
C3sa	90-140	108	8.3	5.0	19.1	0.3	41	5.5	20	54	26	sil	10.0	36.8	67
C4sa	140	78	8.1	5.5	18.3	0.2	43	4.0	24	46	30	cl	10.0	50.0	58
STAGE III: SOLONIZATION															
Lower piedmont plain, Sayf-Abad series (Typic Natrixeralfs)															
A2	0-16	04	7.7	2.0	4.6	1.7	34	0.1	14	43	43	sic	18.6	34.0	5
B21t	16-36	03	7.9	2.0	3.8	1.6	32	0.2	13	35	52	c	20.6	38.7	4
B22t	36-70	07	9.5	38.2	67.0	1.4	33	.0.1	12	31	57	c	21.1	36.8	35
B3t	70-90	13	8.9	34.7	61.0	0.9	37	1.0	14	29	57	c	21.1	38.0	28
C1cs	90-140	12	8.5	33.0	59	0.8	37	5.0	16	28	56	c	16.0	40.1	21
C2	> 140	17	8.3	30.2	55	0.6	36	0.1	15	30	55	c	20.1	45.0	40
STAGE IV: DEALKALIZATION															
Upper piedmont plain, Chartaghi series (Calcic Haploxeralfs)															
A2	0-30	01	8.0	5.0	17.0	0.7	44	0.1	20	50	30	cl-sicl	14	34.2	2
B21t	30-45	01	8.1	0.7	1.7	0.3	47	0.4	14	42	44	sic	13	32.8	2
B22t	45-65	02	8.0	0.9	1.7	0.3	45	0.4	6	42	52	sic	18	34.2	5
IIC	65-135	05	8.0	12.6	38	0.2	29	22.0	38	28	34	cl	17	43.2	6

Table 3. Chemical composition of ground water from representative physiographic area.

Physiography	EC	pH	Anions and cations						
			HCO3	Cl	SO4	Ca	Mg	Na	SAR
	dSm^{-1}		---------- meq l-1 ----------						
Lowland	75	6.3	1	1250	310	50	170	1300	124
Alluvial plain	67	7.3	3	800	205	50	120	800	86
Lower piedmont plain	7.2	7.5	4	46	42	25	35	36	7
Upper piedmont plain	6.8	7.8	3	55	26	24	31	30	6

the pH and the amount of water-dispersible clay are low throughout the profile, mainly due to the presence of excess soluble salts (Table 2). Although the Na content of the soil profile is high, due to the presence of high amount of salt, the Maharlu series does not show any field evidence of clay migration. Gypsum in the profile of Maharlu series (Table 2) might be pedogenic and accumulated by capillary water.

Kamal-Abad Soil Series

In the alluvial plains, approximately 2 m higher than the lowlands, the depth of water table is 2 to 3 m for the most of the year and the first effect on soil formation is a substantial leaching of the salts from the upper part of the profile (Tables 1 and 2).

The desalination is associated with a partial dealkalization and formation of a gypsic horizon. However, at this stage enough salts are still present to prevent the action of Na on clay dispersion. At a further stage of desalination, clay dispersion becomes evident and a third stage is reached.

Sayf-Abad Soil Series

In the lower piedmont plains, auger sampling from the depth of soil profile showed that the water table is deeper than 3 m, therefore, desalination is more pronounced (Tables 1, 2 and 3) and hydrolysis of the Na clay complex causes the pH to be 9.5 or higher. The dispersion of the clay leads to clay migration which is a basic requirement of the formation of natric and argillic horizons. The amount of water-dispersible clay is greater than 65% of the total clay.

The data of Table 2 suggest that exchangeable Na, which is a major cause of clay dispersion and migration (1, 4), becomes more effective at dispersion when the excess salt in the soil solution has been leached. Clay migration apparently formed the continuous clay skins observable in the field (Table 1). The high concentration of water-dispersible clay (Table 2) shows that clay migration is still active. Dispersibility of clay is probably affected by the same factors as swelling of clay. Rowell *et al.* (34) have listed these factors as the type of clay, the concentration and composition of the electrolyte, and the presence of other materials in association with clay such as iron and aluminum.

Chartaghi Soil Series

In the higher parts of the piedmont plains where ground water is deeper and no longer influences the soil-forming process, the Chartaghi soils developed. In this series due to Ca from dissolution of carbonates, Ca is the major cation in exchange sites, therefore, pH and ESP values are lower than the values in Sayf-Abad soils. The soil $CaCO_3$ likely acts as a continuous reservoir for maintaining a low but steady concentration of soluble Ca ions necessary for replacing exchangeable Na of the natric horizon of the Sayf-Abad series to the argillic horizon of the Chartaghi series. The released Na likely leached away, if there was ever any, from the soil profile by precipitation during winters. The low water-dispersible clay content of the Chartaghi series might be due to this ameliorative process.

The dealkalization process corresponds to the steppification of the solonetz (steppified Solonetz) of Kovda *et al.* (25).

Evaluation of Clay Mineralogy

Analysis of clay fraction from each subsurface horizon of the four representative soils of the study sequence revealed that similar minerals were present, but they differed in their abundance (Fig. 3 and Table 4).

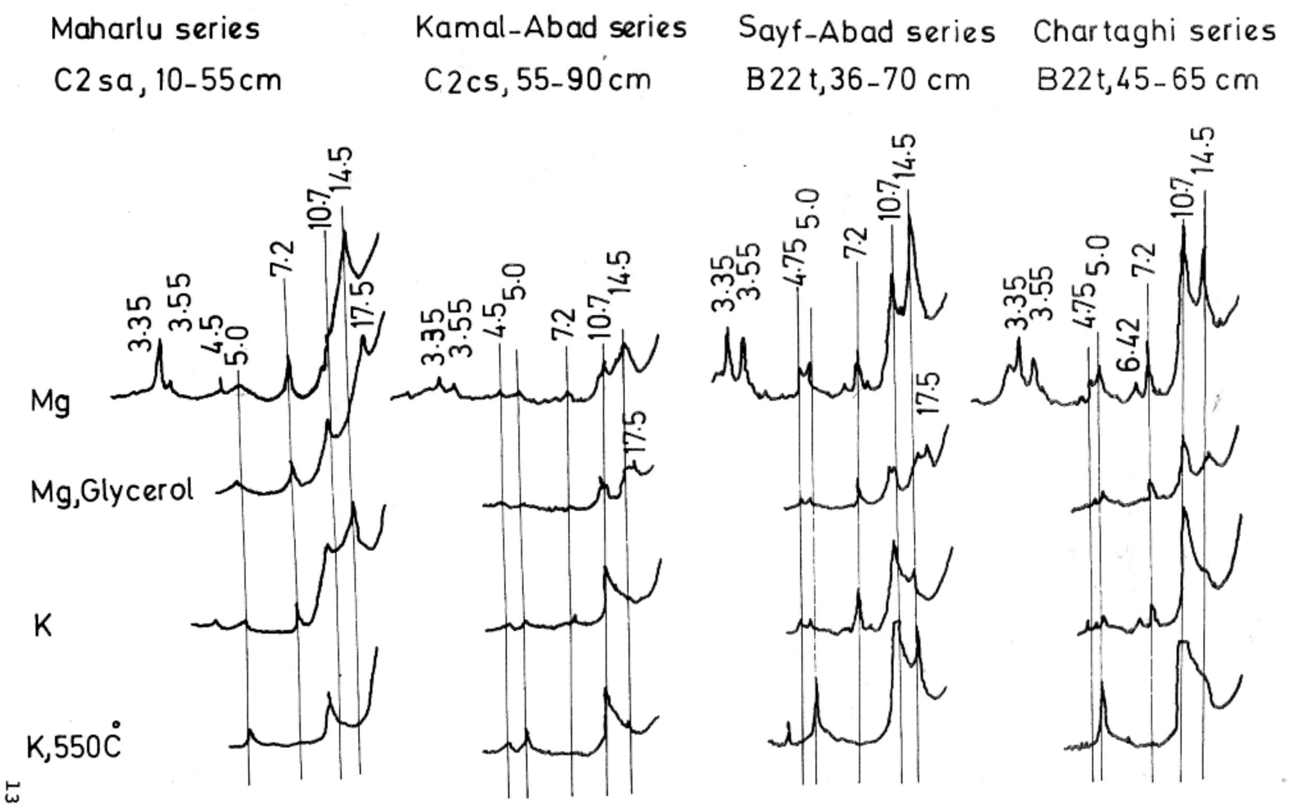

Fig. 3 X-ray diffraction pattern of clay from subsurface horizons of Maharlu, Kamal-Abad, Sayf-Abad and Chartaghi series. (d-values are in A).

Table 4. Semiquantitative analysis of the soil clays.

Horizon	Depth	Palygorskite	Smectite	Illite	Chlorite	Vermiculite	Quartz
	cm	%					
STAGE I :	SALINATION AND ALKALIZATION						
			Lowlant, Maharlu series(Aquollic Salorthids)				
C1sa	0-10	++	++++	++	+	N	+
C2sa	10-55	++	++++	++	+	N	+
C3sa	55-70	++	++++	++	+	N	+
C4sa	70-100	+	++++	++	+	N	+
STAGE II :	DESALINATION						
			Alluvial plain, Kamal-Abad series (Salic Gypsiorthids)				
A1	0-20	+++	+++	+++	++	N	+
C1cs	20-55	+++	+++	++	++	N	+
C2cs	55-90	+++	+++	++	+	N	+
C3sa	90-140	+++	++	++	++	N	+
C4sa	>140	+++	+++	++	+	N	+
STAGE III:	SOLONIZATION						
			Lower piedmont plain, Sayf-Abad series(Typic Natrixeralfs)				
A2	0-16	+++	+	++	++	N	+
B21t	16-36	+++	+++	++	++	N	+
B22t	36-70	+++	++	++	++	N	+
B3t	70-90	+++	+++	++	++	N	+
C1cs	90-140	++	+++	++	++	N	+
C2	>140	++	+++	++	++	N	+
STAGE IV :	DEALKALIZATION						
			Upper piedmont plain, Chartaghi series(Calcic Haploxeralfs)				
A2	0-30	++++	++	++	+	N	+
B21t	30-45	++++	++	++	+	N	+
B22t	45-65	++++	++	++	+	N	+
IIC	65-135	+++	+++	++	+	N	+

* ++++ = 50% , +++ = 25-50% , ++ = 10-25% , + = 10% , N=not detected.

The patterns of Mg-treated, glycerol-solvated specimens (Fig. 3) show the presence of illite, smectite, Fe-chlorite, palygorskite, quartz and trace of vermiculite. In addition to a 10.7 A° peak in X-ray diffractograms, the electron micrography of the Fe-free clay samples confirmed the presence of varying amounts of palygorskite type of clay minerals in all samples (Fig. 4). In Salorthids of the lowlands area (Maharlu) the palygorskite content is <25%. Where a natric horizon is present (Sayf-Abad) the palygorskite content is between 25-50%, and where an argillic horizon (Chartaghi), it increases to 50% or more (Fig. 4). This difference could be attributed to the change in depth to saline and sodic ground water and degree of salt accumulation resulting from variation in topography.

According to Henderson and Robertson (16), and Martin Vivaldi and Robertson (28), 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 (11). Therefore, it may be concluded that the presence of a large quantity of palygorskite or smectite in soils could be due to pedogenic processes. Soil solution moderately rich in silica, Ca, and Mg, may favor the formation of palygorskite and smectite (32), which have similar chemical compositions but different structures. Alkaline and alkaline-earth elements such as those needed for this neoformation may be from the weathering of limestone and dolomitic limestone. Si is fairly ubiquitous in primary and secondary minerals and will also be present as dissolved $Si(OH)_4$ in the ground water. According to Wiersma (38) part of the necessary SiO_2 originates from finely distributed silica present in the limestone. Smectite, which is present only in trace amount in parent rocks, probably forms in the soil from chlorite. Formation of smectite from illite and chlorite has been reported under conditions similar to those of the Sarvestan basin (11, 33). Since smectite is not stable in highly saline and

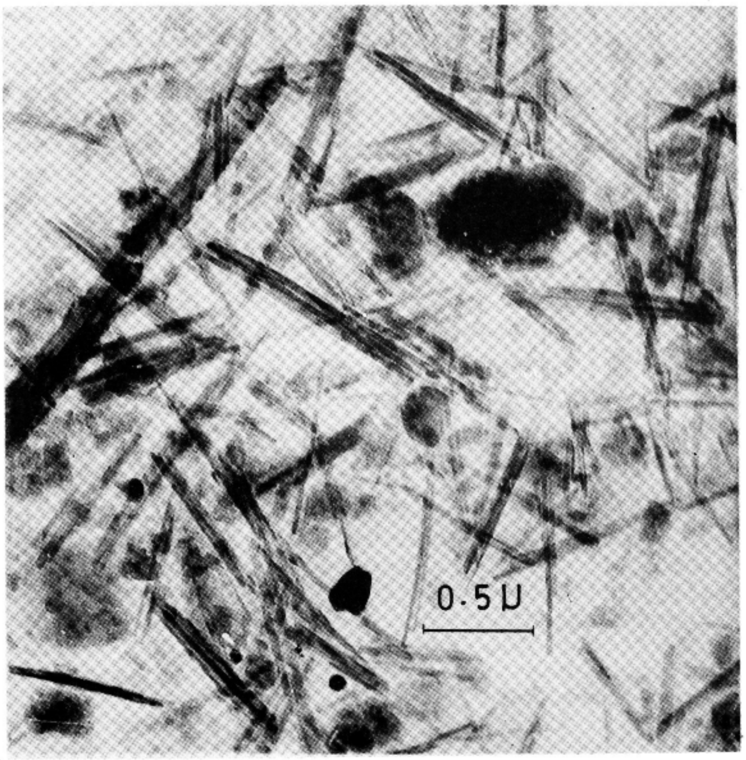

Fig. 4. Electron micrograph (35,000 X) of clay of the Chartaghi series (B22t, 45-65 cm) showing the presence of fibrous (palygorskite) and platy clay minerals.

alkaline conditions (15, 18), therefore, the high amount of smectite minerals in the lowland area (Table 4) is supposed to have been formed outside of the present-day lowland surface, under the influence of fresh water circulation. This mineral under sustained influence of very high salinity and alkalinity gradually decomposes and palygorskite neoforms from decomposition products. The palygorskite present in the area may be of two origins: neoformation from the reaction of Mg and silica present in ground water (27, 29, 31) or diagenetic formation from smectite (9, 17, 38, 39). A decrease in the cation exchange capacity of the clay fraction (Table 2) likely reflects the changes in the clay mineralogy within the sequence (Fig. 3 and Table 4). Therefore, it may be concluded that, as a result of variation in depth to saline and sodic ground water and degree of salt accumulation, resulting from variations in topography, palygorskite increases as smectite decreases. In the lowland area with high smectite and low palygorskite the CEC is high (66.4 meq 100^{-1} g clay) while in the lower piedmont plains with deep ground water and soils with argillic horizon that have low smectite and a high palygorskite contents, the CEC drops to rather low values (34.2 meq 100^{-1} g clay) as the CEC of palygorskite is low.

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