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SOIL GENETICS AS AFFECTED BY TOPOGRAPHY AND DEPTH OF SALINE AND ALKALI GROUND WATER UNDER SEMIARID CONDITIONS IN SOUTHERN IRAN[1]

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ABSTRACT

Soil formation in a toposequence of soils was studied in a highly calcareous parent material under semiarid conditions of southern Iran. Soils with salic horizons (Typic Salorthids) have been formed on a flood plain with shallow ground water, soils with natric horizons (Typic Natrixeralfs) on a lower terrace with moderately deep ground water, and soils with argillic horizons (Calcic Haploxeralfs) on a higher terrace with very deep ground water. Exchangeable Na, the major cause of clay dispersion and migration, is only effective when excess salts have been leached out. Salinization and alkalization, desalinization and solonetzation, and dealkaization are three successive stages in the formation of these soils. X-ray and electron optical analysis indicated that the clay-size minerals are of similar types, but differ in relative occurrence.

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تاثیرپستی وبلندی وعمق سفره آب زیرزمینی شوروقلیا درژنتیک خاک درشرائط نیمه‌خشک جنوب ایران

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خلاصه

تشکیل خاک دریک تاپوسیکونس ازخاکها با موادمادری کاملا" آهکی درشرائط نیمه‌خشک جنوب ایران موردمطالعه قرارگرفت. خاکهای باافق سالیک (تیپیک سال

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اورتید) در دشت سیلابی با سفره آب زیرزمینی کم‌عمق، خاکهای با افق ناتریک (تیپیک ناتری زرالف) در ترسهای پائینی با سفره آب زیرزمینی نسبتا "عمیق وخاکهای با افق آرجیلیک (کلسیک هاپل زرالف) در تراسهای مرتفع با سفره آب زیرزمینی خیلی عمیق تشکیل شده اند. سدیم قابل تبادل بعنوان عامل اصلی درپراکندگی وانتقال رس وقتی مؤثر است که نمکهای محلول اضافی ازخاک خارج شود. شوروقلیا شدن، شوره زدائی وپیدایش حالت سولونتری وقلیا زدائی سه مرحله متوالی درتشکیل این خاکها بحساب میایند. آزمایشات ایکس ری ومیکروسکوپ الکترونی نشان دادکه نوع رس درخاکهای مختلف مشابه بوده حال آنکه میزان نسبی آنها متفاوت میباشد.

INTRODUCTION

The highly calcareous soils form a toposequence along the Kur and Sivand rivers near the town of Marvedasht, about 50 km north of Shiraz. The climate is Mediterranean with an average annual rainfall of 332 mm. The highest and lowest mean monthly temperatures recorded for July and January (1965-1978) are 27.2 and 5.7°C respectively. The soil moisture regime of the study area is "Xeric" (4).

Based on topography and drainage conditions the study catena was subdivided into three major physiographic units: flood plain and lowland, and lower and upper terraces of the Kur river.

The native vegetation of the area contains many species with a zonal distribution determined mainly by soil salinity and depth of saline-sodic ground water. *Glycyrhiza glabra*, *Alhagi camelorum*, *Carthamus oniocanthus*, *Capparis orta* *Achillea millefolium*, *Hultemia persica*, *Salsola* sp., *Lactuca orientali* and *Cynodon dactylon* cover the salt affected soils.

The parent materials of soils are fine textured and highly calcareous materials derived from the surrounding limestone mountains.

The soils are described and classified according to the USDA, Soil Survey Manual (31) and Soil Taxonomy (32), respectively (Table 1).

Table 1. Morphology and classification of the studied toposequence.

Horizon	Depth cm	Munsell color (moist)	Texture†	Structure†	Consistence†	Boundary†	Other components
Upper Terrace							
				Takht-e Jamshid series (Calcic Haploxeralfs)			
Ap	0-20	10YR 4/3	sicl	m2pr±flgr	mf	cs	Common fine and coarse roots
B21tca	20-55	10YR 4/3	c	m3pr	mfi	cs	Thin, patchy clay skins on the ped faces some rounded powdery carbonate bodies
B22tca	55-75	10YR 4/3	sic	m2pr	mfi	gw	Thin, broken clay skins on the ped faces; some mycellium and concretion of carbonate
B23tca	75-120	7.5YR 4/4	sic-c	m1pr	mfi	cs	Moderately thick, broken clay skins on the ped faces; some mycellium and concretion of carbonate; f1d mottles of 10YR 5/8
C	120-150	10YR 5/4	sil-cl	m	mvfi	-	f1d mottles of 10YR 5/8
Lower Terrace							
				Marvedasht series (Typic Natrixeralfs)			
Ap	0-8	10YR 4/4	sicl-cl	f1sbk±f1gr	mf	cs	Many fine roots
B21t	8-65	10YR 5/4	c	m2pr±m1sbk	mfi	cs	Common fine roots; thin, patchy clay skins on the ped faces
B22t	65-95	10YR 4/3	c	c3pr±c3sbk	mfi	cs	Few fine roots; thin, broken clay skins on the ped faces
B23t	95-120	10YR 4/3	c	m2pr±m2sbk	mfi	gw	Thin, patchy clay skins on the ped faces
C	120-150	10YR 4/3	c	m	mvfi	-	Presence of MnO_2 nodules
Flood Plain and Lowland							
				Ahuchar series (Typic Salorthids)			
A1sacs	0-10	7.5YR 4/4	sil	f1pl	mfi	as	Presence of abundant salt and gypsum crystals
C1sag	10-30	10YR 4/3	sic	m	mfi	cs	Very saline; c1d mottles of 5Y6/1
C2sag	30-75	10YR 4/4	sicl	m	mfi	gs	Very saline; c1f mottles of 5Y6/1
C3g	75-150	5YR 4/1	c	m	mf		Saline; m2d mottles of 5Y5/2 and 10Y6/8

† Abbreviation as given in Soil Survey Manual, USDA Handbook No. 18, p. 139, 1951.

± Indicates primary structure that breaks to secondary structure when ruptured.

MATERIALS AND METHODS

Particle-size analysis was determined by the hydrometer (7) and pipette methods (10) using sodium hexametaphosphate as dispersing agent after destruction of $CaCO_3$ and organic matter with 0.5N HCl and 30% H_2O_2, respectively. Soil pH was measured in saturated paste using a Beckman pH meter. Electrical conductivity (EC) of the saturation extract was measured with a conductivity bridge and the results expressed in siemens m^{-1} at 25°C (34). Organic carbon was determined by wet oxidation with chromic acid and back titration with ferrous sulfate (18). Cation exchange capacity (CEC) was determined with 1N NaOAC (pH=8.2) for soil and NH_4OAC (pH=7) for clay (9).

Removal of chemical cementing agents and separation of the different fractions was done according to the methods of Kittrick and Hope (21) and Jackson (19), respectively. Free Fe oxides were removed from clay samples by the citrate-dithionite method (25).

Citrate-dithionite treated clays were dried on glass slide and studied by X-ray diffraction, using a Phillips apparatus with CuKa radiation, a range factor of 400 cps. and a time constant of 1 s at 40 kv and 40 mA was used.

X-ray diffractograms were obtained from Mg-saturated soil clays both with and without glycerol solvation. K-saturated samples were X-rayed after drying at room temperature and after heating at 550°C for 2 hr.

Clay minerals were estimated semi-quantitatively from relative peak intensities of glycerol-treated samples (20). Vermiculite clay mineral was determined quantitatively by the method of Alexiades and Jackson (3).

RESULTS AND DISCUSSION

I. Influence of Topography and Depth of a Highly Saline and Alkali Ground Waters on Soil Genesis

a) Lowland and flood plain area (Ahuchar series). Ahuchar series soils have been formed in lowland and depression areas (Fig. 1). Natural drainage conditions are poor and a highly saline and alkali ground water table is present from the soil surface in winter and to a maximum depth of 150 cm in summer.

All subsurface horizons are in a reduced state and show strong gleying. These soils are saturated with very saline and alkali ground water during the winter period, but are dry in summer, resulting in a salty white crust on the surface. Accumulation of salts at and in the upper horizons also occurs through evaporation of very saline and alkali ground water present at the shallow depths.

The main soil forming processes in these water-logged soils consist of reduction of iron and accumulation of salts. (Tables 1 and 2). The Ahuchar series which represent the first stage of soil formation is characterized by a high accumulation of salts in soil solution and a high sodium adsorption ratio (Tables 1 and 2). This stage of soil formation resembles the salinization and alkalization stages of Kovda *et al.* (22) and Abtahi (1). Source of this ground water is seepage from the Kur River (Fig. 1).

Miljkovic *et al.* (26) and Florea *et al.* (12) attributed the formation of solonchak and solonetz in both Hungary and Yugoslavia to occasional excess of water due to periods of high rainfall, flooding, high water tables, and periods of summer drought. Low permeability of the subsoil in the Ahuchar series (Table 2) is a contributing factor in the formation of this saline-sodic soil.

Presence of excess salts in saline-sodic Ahuchar soil decreases the thickness of the diffuse double layer leading to a decrease in potential hydration, swelling and dispersion.

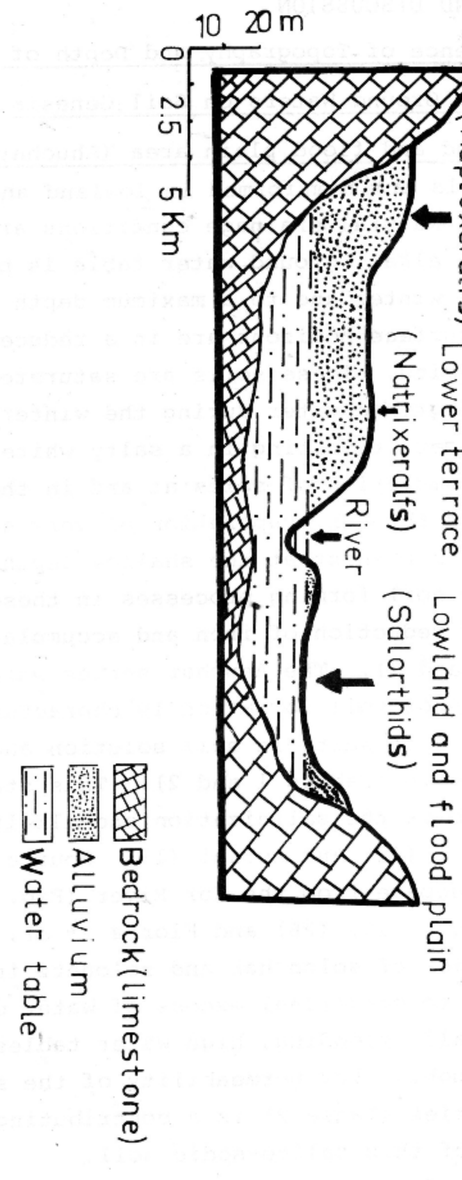

Fig.1_ Cross section of hypothetical toposequence occurring along the Kur and Sivand rivers.

Table 2. Physical and chemical analysis of the studied toposequence.

Horizon	Depth cm	EC_1 Sm^{-1}	pH (paste)	Organic matter	$CaCO_3$	Gypsum	Particle size distribution: Whole Soil Sand	Whole Soil Silt	Whole Soil Clay	Whole Soil Texture	Carbonate-free Sand	Carbonate-free Silt	Carbonate-free Clay	Carbonate-free Texture	CEC Soil	CEC Clay	SAR
				%			%				%				meq $100g^{-1}$		
Upper Terrace																	
					Takht-e Jamshid series (Calcic Haploxeralfs)												
Ap	0-20	0.1	7.9	2.4	35.8	trace	19.4	44.0	39.6	sicl	6.2	55.0	38.8	sicl	16.4	-	0.4
B21tca†	20-55	0.1	8.0	0.9	37.8	trace	20.0	39.4	40.6	c	5.4	43.9	50.7	sic	14.8	43	0.9
B22tca	55-75	0.1	7.6	0.6	38.6	trace	16.5	42.2	41.3	sic	4.2	50.5	45.3	sic	14.8	-	1.6
B23tca	75-120	0.1	7.8	0.4	41.0	trace	19.3	39.4	41.3	sic-c	3.7	53.5	42.8	sic	13.7	-	2.1
C	120-150	0.1	8.0	0.3	43.5	trace	21.3	41.4	27.3	sil-cl	5.3	69.2	25.5	sil	13.2	-	2.4
Lower Terrace																	
					Marvedasht series (Typic Natrixeralfs)												
Ap†	0-8	0.2	8.0	0.7	43.4	trace	19.8	42.1	35	sil-cl	6.8	46.6	46.6	sic	11.3	42.5	6.3
B21t	8-65	0.2	8.3	0.8	41.6	trace	19.4	38	42.6	c	5.1	43.8	51.1	sic	11.7	-	6.7
B22t†	65-95	0.2	8.6	0.1	38.7	trace	13.4	36	50.6	c	2.0	45.7	52.3	sic	17.0	44.0	28.0
B23t	95-120	0.4	8.7	0.1	38.5	trace	15.4	38	46.6	c	2.7	51.9	45.4	sic	15.9	-	39.3
C†	120-150	0.4	8.7	trace	37.7	tracw	21.4	38	40.6	c	8.5	45.1	46.4	sic	14.8	48	36.6
Flood Plan and Lowland																	
					Ahuchar series (Typic Salorthids)												
Alsacs	0-10	10.7	8.3	0.8	30.2	16.2	35.4	57.3	7.3	sil	14.9	51.1	34.0	sicl	14.8	-	72.9
Clsag†	10-30	6.0	8.3	0.6	39.8	trace	15.5	42.0	42.6	sic	1.0	57.5	41.5	sic	21.6	58.0	102.3
C2sag	30-75	5.5	7.9	0.6	45.5	1.5	16.1	48.0	35.9	sicl	2.1	64.7	32.1	sicl	17.6	-	45.3
C3g	75-150	2.8	8.0	0.5	45.6	1.6	14.1	32.0	53.9	c	0.7	49.0	50.3	sic	25.6	-	44.5

† Studied for mineralogical analysis.

All of these contribute to the flocculation of colloidal material. In spite of high SAR values in the Ahuchar series, the pH values of the saturated paste are lower than expected throughout the profiles, probably due to the absence of Na_2CO_3 (Table 2).

b) Lower terrace area (Marvedasht series). As the concentration of salts is lowered (Marvedasht series), some exchangeable Na is hydrolyzed and this causes an increase in soil pH and dispersion and migration of clay. Increase in alkalinity of soils due to leaching of excess soluble salts has been also reported (1, 33). Leaching of the excess soluble salts in the Marvedasht series (desalinization) may also result in dispersion and swelling of the clay, reducing the entry and movement of water. The transition from desalinization to solonetzation is associated with some change in the soil pH values (Table 2). After leaching of excess neutral salts from the Marvesahst soil, hydrolysis of the clay-sodium complex increases pH values up to 8.7 or higher (solonetzation). The highly dispersed sodium-saturated clay in the Marvedasht series moved downward through the soil and accumulated in the B horizons (Table 2). Where the clay accumulates, the soil may develop a dense layer of low permeability with a columnar or prismatic structure (Table 1). In the surface horizons, continuous leaching of this alkali and calcareous soil with rainfall led to the gradual replacement of exchangeable Na by Ca ions solublized from $CaCO_3$, causes decreasing in soil pH. The second stage of soil formation in the studied catena represents the solonetzation stage of Kovda *et al.* classification (22).

c) Soils of upper terrace area (Takht-e Jamshid series). The soils of the Takht-e Jamshid series represent the final stage of soil formation. Calcium from solubilization of the soil $CaCO_3$ has gradually replaced exchageable Na of the Marvedasht soils and consequently Takht-e Jamshid soils developed on the upper terrace. The decrease in pH and SAR values from Marvedasht series toward Takht-e Jamshid series clearly demonstrated this substitution (Table 2). The soil $CaCO_3$ act 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 Marvedasht series to argillic horizon of Takht-e Jamshid series. The released Na leached away from the soil profile by precipitation during winter . The last stage of soil formation of the studied catena is equivalent to steppified solonetz stage of Kovda *et al*. classification (22).

II. Evaluation of Other Soil Characteristics

a) Gleyzation. The shallow ground water of the Ahuchar series has a direct influence on oxidation, reduction and translocation of free Fe oxides. Ferrous Fe is carried in part by water into the lower horizons (Table 1). Under oxidizing conditions (Marvedasht and Takht-e Jamshid series) ferrous Fe is converted to ferric Fe and precipitated resulting in a homogenous brown to dark brown color.

b) Mineralogy of the clay fraction. X-ray diffractograms of the clay fraction from some horizons of the soils revealed that the clay-size minerals were more or less similar in types, but different in the relative occurrence (Fig. 2). Patterns of Mg-treated, glycerol-solvated specimens show the presence of smectite, chlorite, vermiculite, attapulgite, illite, and quartz. In addition to a 10.2°A peak in the X-ray diffractograms (Fig. 2), electron micrographs of the clay samples confirmed the presence of different amounts of an attapulgite-type clay minerals in all samples (14).

Drainage class and salinity show a definite effect on the relative abundances of illite, chlorite, and smectite minerals (Table 3 and Fig. 2). The more poorly drained member of the catena (Ahuchar series) has been subjected to greatest weathering. Clay mineral distribution and CEC of some clay smectite formation than the well-drained members (Marvedasht and Takht-e Jamshid series). Clay minerals distribution and CEC of some clay samples from each profile support this hypothesis (Tables 2 and 3). The soils on the upper slopes are dominantly illitic and chloritic,

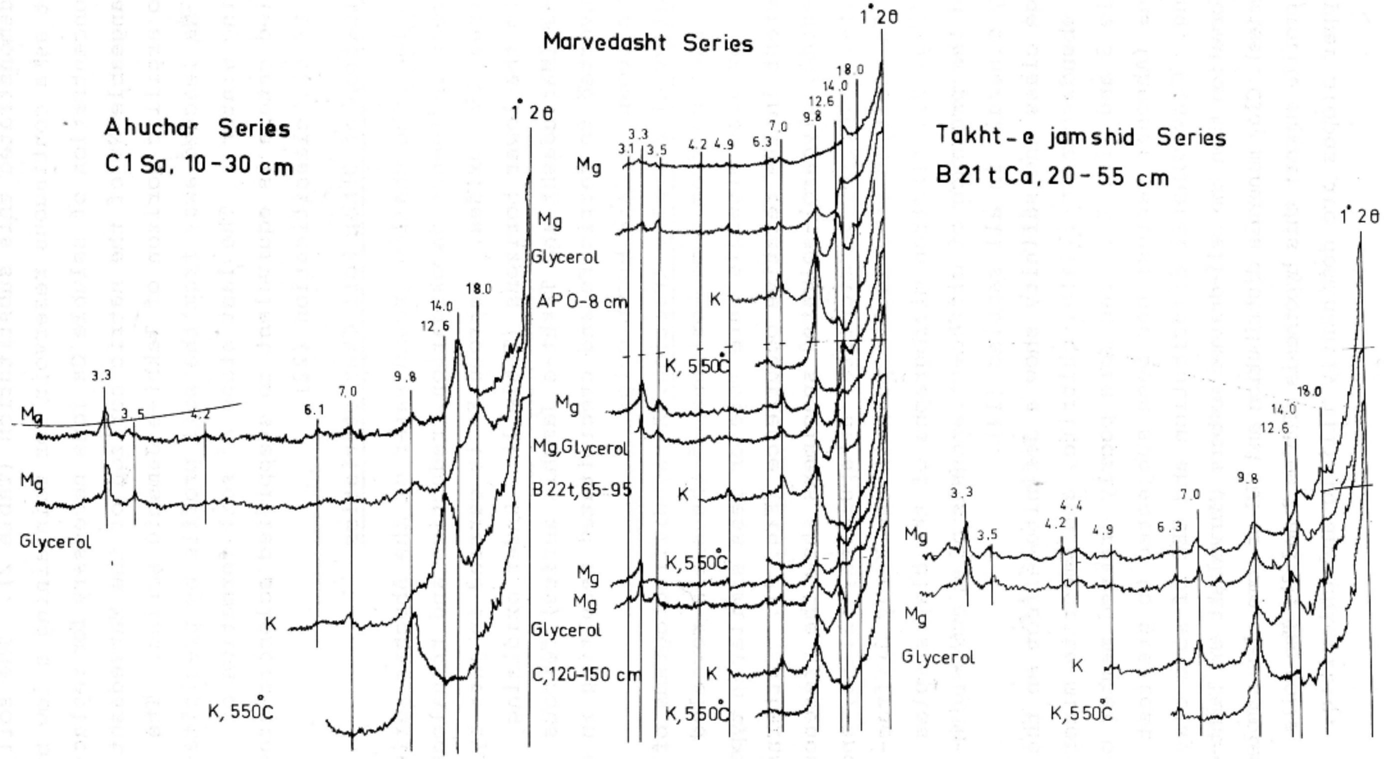

Fig. 2 _X_ ray diffractograms of clay fractions (d values in Å)

Table 3. Semiquantitative analysis of soil clays.†

Horizon	Depth cm	Palygorskite	Smectite	Illite %	Chlorite	Vermiculite	Quartz
Upper Terrace							
		Takht-e Jamshid series (Calcic Haploxeralfs)					
B21tca	20-55	+++	+	++	++	++	++
Lower Terrace							
		Marvedasht series (Typic Natrixeralfs)					
Ap	0-8	+	++	++	+	++	+
B22t	65-95	+	++	++	+	++	++
C	120-150	+	++	+	+	++	++
Flood Plain and Lowland							
		Ahuchar series (Typic Salorthids)					
Clsag	10-30	+	+++	+	+	++	+

† +++ = 25-50%, ++ = 10-25%, + = 10%

whereas those of the lower slopes are predominantly smectitic type. This observation agrees with those of Gawande *et al.* (13) who believed that restricted drainage inhibits the leaching of bases and leads to the formation of a smectite clay. Ferrel *et al.* (11) showed that with increasing salinity, smectite content increased and as a direct consequence CEC was also increased. Gleyzation in the Ahuchar series may favor the accumulation of smectite owing to an adequate supply of Mg and Fe under poor drainage. In the Ahuchar series, mica is more likely to be transformed to hydromica and then to expanding layer minerals such as smectite. Bradley (8) and Jackson (17) found this sequence of clay formation in other parts of the world. In general, two types of smectites can be distinguished: transformation smectites formed by loss of ions from pre-existing silicate clays such as illite (29), and neogenetic smectites formed from ions precipitated directly from solution (6). The smectite of the Ahuchar series is possibly of the transforming type. X-ray diffraction patterns of Mg-treated, glycerol-solvated treatments confirm the former hypothesis (Fig. 2). As shown in Fig. 2, the more intense 18 Å peak of smectite and less intense 10 Å peak of illite appeared in samples of waterlogged and lowland soils. Formation of smectite from chlorite and illite in Iranian soils has also been reported (1, 2, 15).

Formation of smectite in the Ahuchar series may continue before the stage of desalinization and alkalization is reached in the Marvedasht series where smectite is converted to palygorskite (Table 3). This transformation is due to the high alkalinity of desalinized soils (1, 5). Millot (28) suggested that the neogenetic sequence of montmorillonite-palygorskite – sepiolite exists in marine and lacustrine sediments due to a gradually increasing Mg/Al ratio in the precipitating solution. This is quite likely in the slightly alkali calcareous soil which, as outlined above, tends to maintain a very low Al content but a relatively high Mg concentration. Calcareous soils of the study area provide a buffered alkali environment, which is apparently needed for palygorskite formation (30). Alkaline and alkaline-earth elements which are necessary for neoformation of palygorskite, may be derived from the weathering of dolomitic limestone parent rocks. According to Wiersma (35), part of the required SiO_2 originates from finely distributed silica present in limestone.

According to the Henderson and Robertson (15), limestones of southern Iran contain only minor amounts of palygorskite. Therefore, the palygorskite present in soils of the area may be of two origins: neoformation from the reaction of Mg and silica present in the ground water (23, 24, 27), or diagenetic formation from smectite (5, 16, 35). Impeded drainage and temporary water-logging in fine-textured, low-lying soils of the Ahuchar series would enhance precipitation of palygorskite. Singer and Norrish (30) reported that palygorskite appeared to be unstable in most soils and persisted only where leaching was restricted.

As a result of this investigation, it may be concluded that the soils of the study area form a catena with marked differences in the physical, chemical, morphological, and mineralogical properties. These differences appear to be due to variations in topography and the depth of saline-sodic ground water. Three stages in the formation of the soils could be recognized:

1. Salinization and alkalization . The Ahuchar series appear to represent the salinization and alkalization stage. In this stage, saline-sodic soils are formed due to the evaporation of shallow saline and alkali water during dry seasons. Presence of excess salts in saline-sodic soils of the Ahuchar series leads to an increase in flocculation of colloidal materials and as a result pH is maintained below 8.5.

2. Desalinization and solonetzation. As the concentration of the salts is lowered in the Marvedasht series, some of the exchangeable Na is hydrolyzed. This causes an increase in soil pH and dispersity of the colloidal materials. Highly dispersed sodium saturated clay is transported downward through the soil and accumulates in lower layers.

4. Dealkalization. Present-day formation of secondary $CaCO_3$ in the natric horizon may, however, indicate the development towards dealkalinization in the Takht-e Jamshid series. In this stage, Ca from solubilization of the soil $CaCO_3$ replaces exchangeable Na and due to this substitution pH and SAR values decrease from the Marvedasht series toward the Takht-e Jamshid series.

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