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GENESIS, MORPHOLOGY, CHEMICAL AND MINERALOGICAL STUDIES OF SOILS OF DASHT-E ARJAN INTERMONTANE BASIN[1]

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ABSTRACT

Soil formation under semiarid conditions was studied in highly calcareous parent materials of the 5000 ha Dasht-e Arjan Basin in southern Iran. A soil map was drawn on aerial photographs and later trasferred to a topographic map on a scale of 1:5000, which was later reduced to 1:20000. The soils of the study area were mapped at the series level. Physiographic position, morphology, physical, chemical and mineralogical characteristics of each pedon formed the basis for defining the series. Five different soil series were distinguished; and these were strictly related to the physiographic units: Chorab series (Typic Xerorthents) on the alluvial-colluvial fans, Arjan (Fluventic Xerochrepts), Marreh (Calcixerollic Xerochrepts), and Sedeh series (Flüvaquentic Haplaquolls) on the piedmont alluvial plains, and Salman series (Aeric Haplaquepts) on the lowlands. X-ray diffraction and electron optical analyses indicated that olay minerals present in the soils were more or less similar in types, but differed in their relative occurrence. The soils on the upper slopes are dominantly illitic, whereas those of the lower slopes are predominantly montmorillonitic.

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مطالعه تکوینی، مورفولوژیکی ،شیمیائی ومینرالوژیکی خاکهای حوضه دشت ارژن

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خلاصه

تشکیل خاک برروی مواد مادری کاملاً آهکی درتحت شرائط نیمه خشک درحوضه پنج هزار

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هکتاری دشت ارژن واقع در جنوب ایران مورد مطالعه قرار گرفت. ابتدا با کمک عکس های هوائی یک نقشه خاک تهیه و بعداً "برروی نقشه توپوگرافیکی بمقیاس ۱:۵۰۰۰ منتقل گردید و در پایان اشل نقشه تا حد ۱:۲۰۰۰۰ کوچک گردید. براساس موقعیت فیزیوگرافیکی، مشخصات مرفولوژیکی وفیزیکی وشیمیائی ومینرالوژیکی هر پدن سری بندی خاک تعیین گردید. پنج سری خاک که کاملاً" وابسته به فیزیوگرافی های معین میباشند بشرح زیر تشخیص داده شد: سری چراب (تیپیک زراورتنت)برروی رسوبات آبرفتی وواریزه ای بادبزنی شکل ، سری های ارژن (فلوونتیک زراوکریپت) مره (کلسی زراولیک زراوکرپت) وسده (فلوواکونتیک هاپل اکوال) برروی دشت های رسوبی دامنه ای وسری سلمان (آاریک هاپل اکوپت)درزمین های پست . آزمایشات اشعه ایکس و میکروسکوپ الکترونی نشان دادکه نوع رس درخاکهای مختلف مشابه بوده وحال آنکه میزان نسبی آنها متفاوت میباشد. خاکهای واقع برروی شیب های مرتفع بیشتر از نوع ایلیتکی بوده، درصورتیکه خاکهای واقع برروی شیب های پائین بیشتر از نوع مونت موریلونیتیک میباشند.

INTRODUCTION

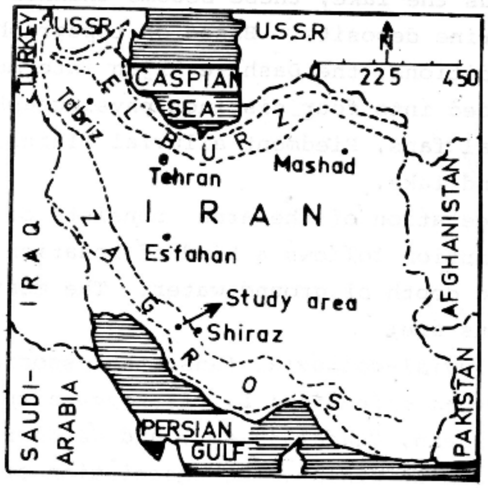
The study area, which is a typical intermontane basin, lies in southern Iran, 63 km west of Shiraz (Fig. 1). The basin is 8 to 10 km long and 4 to 6 km wide with a total area of about 5000 ha. The altitude of the basin varies from 2000 m above mean sea level near the lake surface, to 2500 m above mean sea level at the foot of the mountains. The lake extends from 400 ha in dry seasons to 2400 ha during winters.

The climate is thermomediterranean with an average annual precipitation of 698 mm (1965-1978). The highest and lowest mean monthly temp (1965-1978) are 21.6 and 0.25°C for July and January, respectively.

Soils of the basin have a "Xeric" moisture regime according to the soil moisture and temperature regime map of Iran (5). The soil temperature regime is calculated to be "Mesic".

The geological formations in chronological order are: Sarvak (Upper Cretaceous), Gurpi-pabdeh (Upper Cretaceous-Eocene), Jahrum (Eocene), Asmari (Oligocene), Razak or Gachsaran (Early Miocene), and Alluvial deposits of the Quaternary period (29).

The Dasht-e Arjan intermontane basin is a graben formed by the action of two parallel faults. It contains a playa lake, which is almost dry during the warm, dry summer months. The area surrounding the lake is composed of alluvial-colluvial



Location of Dasht_e Arjan area in Iran.

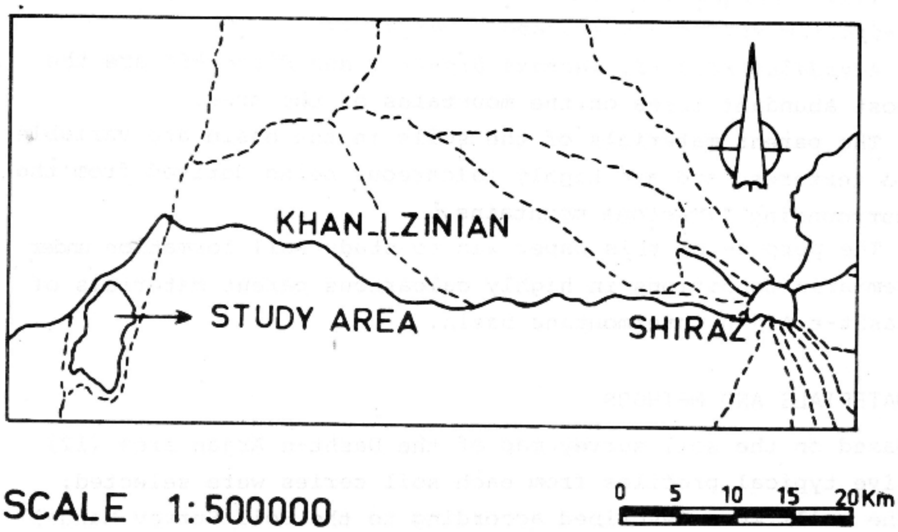


Fig.1. Location map of Dasht_e Arjan intermontane basin.

deposits. Towards the lake, these become thinner and are replaced by lacustrine deposits. Based on topography, lithology and drainage conditions, the Dasht-e Arjan intermontane basin has been subdivided into four distinct physiographic units: Alluvial-colluvial fans, Piedmont alluvial plains, Lowlands, and Marshlands and lake.

The natural vegetation of the area consists of many species and their distribution follows a kind of zonation controlled by topography and depth of ground water. The most important plant associations are:

On gravelly alluvial-colluvial fans, the association of *Artemisia* sp., *Nonea spinosinma* L., *Astragalus* sp., *Carthamus* sp., *Alhagi camelorum*, *Gundellia* sp., and *Centaurea* sp.

In piedmont alluvial plains, the association of *Alhagi camelorum*, *Eryngium* sp., *Astragalus* sp., *Cichorium* sp., *Taraxacum* sp., *Salvia* sp., *Gundellia* sp., *Nonea* sp., *Turgenia* sp., *Artemisia annua* L., *Crisium* sp., *Carthamus* sp. and *Gramineae*.

In lowlands and lacustrine deposits, the association of *Plantago arenaria* W.K., *Salvia* sp., *Mentha aquatica* L., *Trifolium* sp., *Nonea* sp. and *Gramineae*.

Amygdalus reuteri, *Quercus brantii*, and *Pistachio* are the most abundant trees on the mountains of the area.

The parent materials of the soils in the basin are variable in textures, and are highly calcareous being derived from the surrounding limestone mountains.

The purpose of this paper was to study soil formation under semiarid conditions in highly calcareous parent materials of Dasht-e Arjan intermontane basin.

MATERIALS AND METHODS

Based on the soil survey map of the Dasht-e Arjan area (12) five typical profiles from each soil series were selected. The soils were described according to the Soil Survey Manual (35) and USDA Soil Taxonomy (36), respectively (Table 1).

Particle-size analyses were made by the pipette method (13)

Table 1. Morphology and classification of the soils studied.

Horizon	Depth cm	Munsell color (moist)	Texture[†]	Structure[†]	Consistence[†]	Boundary[†]	Other components
SOIL OF ALLUVIAL-COLLUVIAL FAN							
				Chorab series (Typic Xerorthents)			
Ap	0-12	10YR3/3.5	gl-gcl	flgr-flpl	mfr	gs	Common fine roots; 20-30% fine and coarse gravel
AC	12-32	10YR4/4	gl	flsbk	mfi	gs	Few medium roots; 30-40% fine and coarse gravel
IICI	32-100	-	-	-	-	-	Compacted layer of boulder and stone
SOIL OF PIEDMONT-ALLUVIAL PLAIN							
				Arjan series (Fluventic Xerochrepts)			
Ap	0-20	10YR4/3	sil	flgr-flsbk	mfr	gs	Common fine and coarse roots
B2	20-64	10YR5/3	l	m2sbk	fi	gs	Few coarse roots; redistribution of lime around pores
B3	64-88	10YR5/4	l	m2sbk-m	fi	gs	
C	88-150	10YR5/4	l	m	fi	-	
				Marreh series (Calcixerollic Xerochrepts)			
A1	0-15	10YR3/3 and 7.5YR3/2	cl	flsbk	mfi	gs	Few medium and coarse roots
B1	15-43	10YR4/4	cl	m1sbk	mfi	cs	Few medium and coarse roots
B21ca	43-60	10YR5/4	cl	m2abk	mvfi	as	Few rounded carbonate nodules
B22ca	60-107	10YR4.5/4	cl	m2abk	mvfi	gi	Many rounded carbonate nodules; flf mottles of 10YR6/6
C	107-150	10YR5/4	l	m	mfi	-	c2d mottle of 10YR6/6
				Sedeh series (Fluvaquentic Haplaquolls)			
Ap	0-28	10YR3/2	cl	m3gr	mfr	gs	Many fine to coarse roots
B2	28-55	10YR5/3	cl	m2gr-flsbk	mfr	cs	Many fine to coarse roots; C2d mottles of 10YR6/6; patchy thin cutans probably clay skins
Cg	55-90	2.5YR5/2	cl	m-mlabk	mfr	as	m2p mottles of 10YR7/6
IICg	90-150	2.5Y5/2	scl-cl	m	mfr	-	m2p mottles of 10YR6/6
SOIL OF LOWLAND							
				Salman series (Aeric Haplaquepts)			
A1	0-10	2.5Y5/2	cl	flgr	mfr	as	Few roots
B21g	10-23	2.5Y5/2	cl	m2sbk	ws, wp	gs	Few fine tubular pores
B22g	23-68	5Y5/2 to 5Y6/2	c	m2abk to m2sbk	wvp, wvp	gs	
B3g	68-100	5Y6/2	c	m1sbk-m	wvs, wvp	gs	
Cg	100-150	5Y6/2	c	m	wvs, wvp	-	

[†]Symbols used according to abbreviations given in Soil Survey Manual, USDA Handb. No. 18, p. 139, 1951.

after destruction of $CaCO_3$ and organic matter with 2M HCl and 30% H_2O_2, respectively. Soil pH was measured in a saturated soil paste using a Beckman pH meter. Electrical conductivity (EC) of the saturated extract was measured and the results were expressed in siemens m^{-1} at 25°C (37). Alkaline-earth carbonates were determined (37). Organic carbon in the soil was measured by the wet oxidation method of Walkley and Black (22). Cation exchange capacity (CEC) was determined by 1M NaOAc (pH = 8.2) for soil samples and 1M NH_4OAc (pH = 7) for clay fractions (11).

Separation of different size fraction for mineralogical analyses was done according to the methods of Kittrick and Hope (26) and Jackson (23). Free iron oxides were removed from clay samples by citrate-dithionite (28).

Citrate-dithionite treated clays were dried on glass slides and examined by 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 soil clays both before and after glycerol solvation. Potassium-saturated samples were X-rayed after drying at room temp and after heating at 550°C.

Electron micrographs of citrate-dithionite treated clays were obtained with a Philips SM 300 electron microscope following the techniques of Bates (6).

The electron micrographs and the 10.7Å peak of the X-ray diffractograms were used for the semi-quantitative determination of palygorskite (1). Since no feldspars were observed in the clay fraction, the percentage of illite was obtained from total K_2O content of the clay (23).

Vermiculite clay mineral was determined quantitatively by the method of Alexiades and Jackson (4). Quantification of other minerals was estimated from their relative peak intensities using the glycerol-treated samples (24).

RESULTS AND DISCUSSION

Influence of Topography on Soil Genesis

The two main factors influenced by topography, the degree of carbonate accumulation and the depth of ground water are responsible for genesis of the soils of the studied area.

Calcium Carbonate Distribution

Soils with no $CaCO_3$ redistribution (Chorab series) occur in alluvial-colluvial fan deposits of Holocene age (Tables 1 and 2). Soils which occur on abrupt slopes are typically shallow and gravelly with weak horizonization. Carbonates are mostly present as limestone fragments and their distribution in the profile follows the initial content of the parent material. Lack of any diagnostic horizon, except an ochric epipedon, is due to the instability of the soil surface resulting from periodic additions of sediment, which further reduces the time available for pedological neoformation. Since run off is greater on sloping areas than from nearly level areas, less leaching and no carbonate accumulation occur on slopes. As Brewer and Sleeman (8) reported, in young soils formed on calcareous sediments, carbonates commonly occur as crystallites disseminated through the plasma of the S-matrix.

Soils on flat to gently sloping piedmont plains of Late Pleistocene age (Arjan series) exhibit greater evidence of soil development than the Chorab series. They have a cambic horizon as reflected in their structural development and carbonate redistribution (Tables 1 and 2). According to Gile (14) and Gile and Hawley (15), cambic horizons are characterized by sufficient alteration of the original parent material to form structural units, redistribute carbonates, and accumulate small amount of silicate clays. Gile and Hawley (15) and Gile (16) explained that carbonate redistribution in B horizons may be due to leaching by fluctuating ground water, rainfall, and irrigation water used for farming purposes. Abtahi (3) believed that carbonate redistribution was caused

Table 2. Physical and chemical analysis of soils.

Horizon	Depth	EC	pH (paste)	Organic matter	Particle size distribution CaCO$_3$	Sand	Silt	Clay	Texture	Free Fe$_2$O$_3$	CEC Soil	CEC Clay
	cm	Sm^{-1}		%	%	%	%	%		%	meq 100g^{-1}	meq 100g^{-1}
SOIL OF ALLUVIAL-COLLUVIAL FAN												
				Chorab series (Typic Xerorthents)								
Ap	0-12	0.03	7.7	3.1	60.0	42.3	31.1	26.6	gl-gcl	-	16.7	-
Ac†	12-32	0.03	7.8	1.9	65.1	46.0	25.7	28.3	gl	2.8	14.1	54.0
IICI	32-100	-	-	-	-	-	-	-	-	-	-	-
SOIL OF PIEDMONT-ALLUVIAL PLAIN												
				Arjan series (Fluventic Xerochrepts)								
Ap	0-20	0.09	7.7	3.7	60.2	30.7	53.1	16.2	sil	-	18.5	-
B2†	20-64	0.05	7.9	1.5	56.2	30.0	47.4	22.6	l	3.1	17.9	64
B3	64-88	0.05	8.1	1.1	58.3	28.3	47.7	24.0	l	-	19.1	-
C	88-150	0.1	8.0	0.7	65.0	28.0	47.3	24.7	l	-	18.3	-
				Marreh series (Calcixerollic Xerochrepts)								
A1	0-15	0.05	7.7	4.1	38.1	28.4	39.0	32.6	cl	-	23.3	-
B1†	15-43	0.04	7.8	1.5	48.9	35.3	34.1	30.6	cl	2.9	21.5	64
B21ca	43-60	0.03	8.1	1.3	63.7	25.8	37.7	37.5	cl	-	25.0	-
B22ca	60-107	0.04	7.9	1.2	58.2	21.8	39.7	38.5	cl	-	29.8	-
C	107-150	0.04	8.0	0.4	57.5	33.4	44	22.6	l	-	15.7	-
				Sedeh series (Fluvaquentic Haplaquolls)								
Ap	0-28	0.04	7.8	6.4	58.8	27.5	39.0	33.5	cl	-	32.9	-
B2†	28-55	0.03	8.0	2.6	65.1	34.7	33.7	31.6	cl	2.7	26.4	70.0
Cg	55-90	0.03	7.9	1.3	62.5	31.9	33.4	34.7	cl	-	24.1	-
IICg	90-150	0.04	8.0	0.9	68.2	44.4	27.0	28.6	scl-cl	-	17.9	-
SOIL OF LOWLAND												
				Salman series (Aeric Haplaquepts)								
A1	0-10	0.23	7.8	3.0	61.7	21.6	41.7	36.7	cl	-	23.5	-
B21g†	10-23	0.06	7.9	1.7	65.3	24.7	39.1	26.2	cl	2.2	19.8	82.0
B22g	23-68	0.07	7.9	1.4	61.5	21.4	34	44.6	c	-	19.1	-
B3g	68-100	0.06	7.9	1.1	59.3	15.8	28.3	55.9	c	-	24.8	-
Cg	100-150	0.12	7.8	1.0	56.7	19.1	27.7	53.2	c	-	44.1	-

†Studied for mineralogical analysis.

by their dissolution and leaching from the upper profile during the cold wet winter and their subsequent precipitation in the lower profile during the hot dry summer. Loss of carbonates from surface horizons may be compensated for a continuous recharge of $CaCO_3$ from sediment deposition from higher limestone outcrops (1). Carbonate redistribution in the fine-textured soils of the Arjan series is manifested by the presence of an underlying horizon with a higher carbonate content. All evidence of sediment stratification has been destroyed in the solum. Furthermore, the cambic horizon has developed moderately strong, angular blocky structures.

Profile development on older alluvial materials (Early and Middle Pleistocene) of flat to undulating piedmont plains (Marreh series) represents a more advanced stage of soil formation. It is distinguished from Arjan series by a considerable accumulation of rounded, powdery carbonate bodies and medium to coarse nodules in the $B_{22}Ca$ horizon. This stage of soil formation resembles the strong calcic horizon of Gile's classification (14). Gile and Hawley (15) and Ruellan (30) believed that there is a relationship between the form and degree of concentration of carbonates and soil age. In most instances two processes control profile carbonate concentrations: $CaCO_3$ is moved down from the surface soil during the rainy seasons and is mixed with that which is moving upward from the water table during dry seasons (15, 20, 38). These $CaCO_3$ concretions harden during hot and dry summers. According to Brewer and Sleeman (8), concretions usually occur only where there is a strong concentration to form a "Pan" in which the concentric layers usually enclose a nodular form and act as a cement. Carbonate accumulation and macroscopic calcite were formed in the Marreh series at depths where the profile is frequently wet, and in places most accessible to percolating water ($B_{21}Ca$ and $B_{22}Ca$). Wieder and Yaalon (39) reported that nodular formation started in calcic horizons which had become enriched with microcalcite.

Calcic horizons formed at or just below the depth of seasonal wetting are enriched by $CaCO_3$ as the saturated soil solution slowly moves downward to layers of higher moisture tension, where $CaCO_3$ is precipitated as microcalcite. Subsequently, as the density of the calcite layer increases the segregation occurs *in situ*. Thus, the nodules formed in Bca horizon of the Marreh series gradually become compacted by repeated wetting and drying cycles.

There is a slight accumulation of silicate clays in the calcic horizon of the Marreh soil series (Table 2). This is in agreement with reports in the literatures (15, 16, 31), where analysis of clay on a carbonate-free basis indicated that many calcic horizons also were the zone of maximum clay accumulation.

Effect of Ground Water

Well-drained (oxidized soils have a brownish color and low organic matter content, whereas poorly drained (reduced) soils have bluish-green to gray colors and higher organic matter content (Table 2). Simonson and Boersma (34) believed that the color features are not independent of one another and are considered jointly in the morphological assessment of the natural drainage class of soil. Organic matter content seems to be closely related to the depth of the water table. As the water table moves closer to the soil surface, anaerobic conditions favorable to organic matter accumulation become more pronounced (25, 32).

Development of strong angular surface structures in the somewhat poorly drained Sedeh soil series was due to the high organic matter and carbonate content present in the area (17, 18, 19). On the lake margins, water logging is more pronounced and has a major influence on the morphology of the Salman soil series. The most important difference between the submerged soils of the Salman series and the well-drained soils (Chorab and Arjan series) is that the former are in a reduced state. Except for a thin, brown, oxidized surface layer, which is sometimes absent, (Salman series), submerged soils are gray to greenish, have a low oxidation-reduction potential and contain NH_4^+ , H_2S , Mn^{2+} , Fe^{2+} , and CH_4. Schilling (33) reported that depth to specific gray mottling gave a good estimate of the wet season mean high water table. The lower organic matter content of the Salman series (Table 2) is due to the submergence of these soils during most of the year, which restricts plant growth. In the Sedeh series, during dry seasons, the water table is at 2 m below the ground surface, which is favorable for growth of the natural vegetations. The main genetic process in the soils with submerged water (Salman series) is reduction followed by segregation or removal of Fe as a result of saturation by a high water table. Other processes causing alteration of the parent material in the Salman series are leaching of carbonates, physical and chemical weathering, and development of prismatic structure.

Evaluation of Other Soil Properties

a) Texture. The Holocene alluvial-colluvial fan deposits (Chorab series) are coarser in texture (gravelly loam, Table 2) than the other soils of the piedmont plains and the lowlands (silty clay loam to clay; Table 2). Soil profiles are typically very shallow and gravelly near the foothills, but they become deeper and finer in texture towards the plain. During wet periods, fan deposition was probably accelerated and consequently coarser textures were produced, while in dry periods, the rate of deposition probably slowed down and finer textures were formed.

South-east of Dasht-e Arjan, the Salman series soils developed in very fine lacustrine deposits of pleistocene age. Due to the clay texture of the soil a network of mud-cracks (Takyr) were formed in their surface horizon.

b) Mineralogy of the clay fraction. X-ray diffraction of less than 2 μm fraction from each subsurface horizon of five representative soils revealed that similar minerals were present, but they differed in their relative occurrence (Fig. 2). This difference could be attributed to the change in drainage conditions resulted from variations in topography.

The patterns of Mg-treated, glycerol-solvated specimens (Fig. 2) show the presence of illite, smectite, Fe-chlorite palygorskite, quartz with traces of vermuculite and interstratified clays. In addition to a 10.7Å peak in X-ray diffractograms, the electron micrography of the Fe-free clay samples confirmed the presence of varying amounts of a palygorskite type of clay mineral in all samples (12).

Table 3 shows the relative abundance of clay minerals calcultaed from the Mg-saturated, glycerol-solvated treatments. In establishing the relative abundance of each constituent, all components were compared to the illite phase within each sample. Since no feldspars were observed in clay fraction, the percentage of illite was obtained from K_2O content of the clay (23). Intensity difference of the 10Å and 18Å reflections in the glycerol-treated samples were used in comparing the illite and smectite components. Data obtained by Bradley (7) show that the intensity values for illite as calculated above must be multiplied by a factor of four before comparison can be made with intensity values at 18Å for smectite. The presence of 7.0-7.2Å peaks complicated differentiation of chlorite from kaolinite. According to Brindley (9), chlorite rich in Fe give relatively weak first- and third-order reflection and stronger second-and fourth-order reflections. The presence of 4.7Å confirms presence of chlorite. Under these circumstances the presence of chlorite prevents determining the presence or absence of kaolinite. The 3.5Å maximum for chlorite can be compared directly with the 3.3Å reflections for illite as a mean of relative estimation within a given sample. In as much as 3.5Å and 7.15Å peaks are of comparable intensity, these changes can be observed by noting the effect of glycolation on the 7.15Å

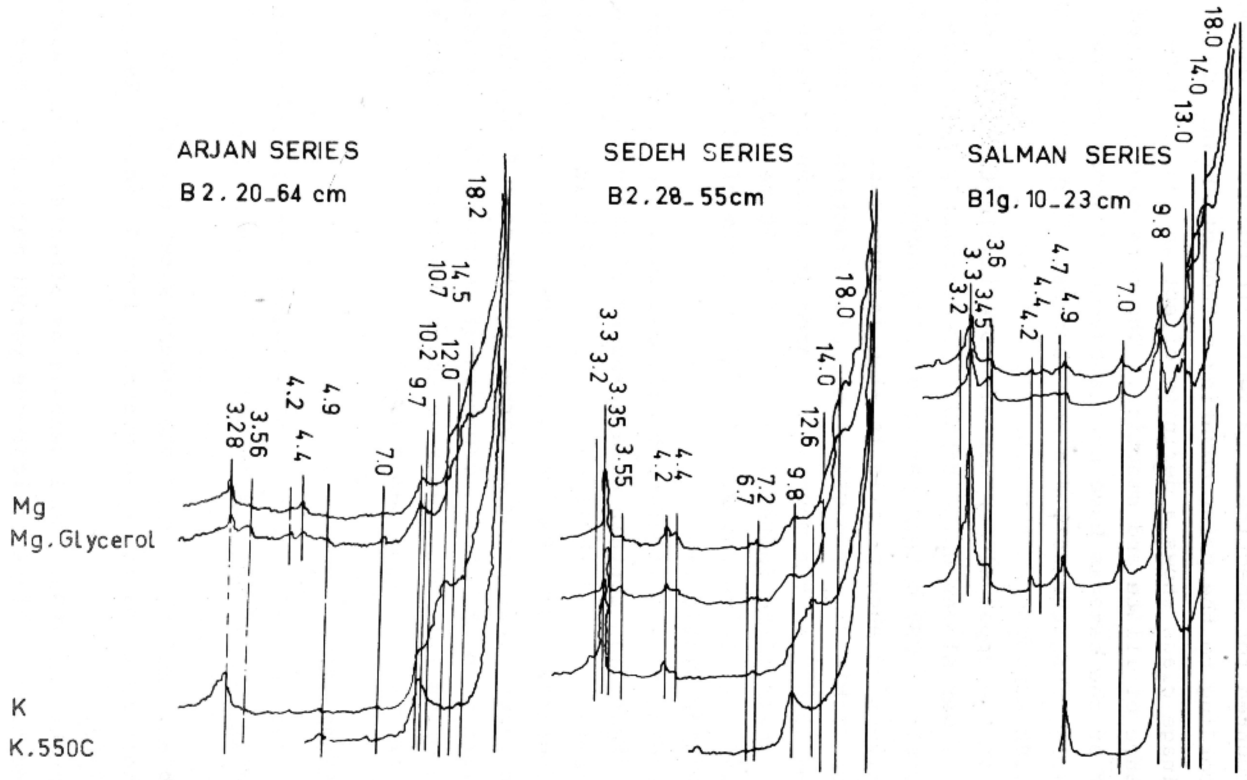


Fig 2. X_ray diffraction pattern of clay from subsurface horizons of Arjan. Sedeh and Salman series. Figures are d_values in Å

reflection. Reduction in intensity following glycolation can be accounted for smectite. Palygorskite content was estimated according to the point counting method of Abtahi (1).

Drainage class shows a definite effect on the relative abundance of illite and smectite. The more poorly drained member of the catenas have been subjected to more severe weathering than the well drained members. Clay mineral distribution supports this hypothesis (Tables 2 and 3). The soils on the upper slopes contain more illite than the soils of the lower slopes which contain predominantly smectities. The result of CEC determination of clay samples of subsurface of horizons of each profile is also in agreement with this concept (Table 2). The CEC of the clay fraction which is 46.6 me $100g^{-1}$ in the mountainous area increases to 54 me $100g^{-1}$ towards the foothills and to 64 to 70 me $100g^{-1}$ in the piedmont plains and finally to a maximum of 82 me $100g^{-1}$ in lowlands (Table 2).

According to the literature (10, 21, 27), the limestones of southern Iran contain equal amounts of illite, chlorite and quartz. Therefore, it may be concluded that as a result of pedogenesis, smectite which is present only in trace amount in the parent rock probably formed in the soil from chlorite or illite or both. Soil formation of smectite from illite and chlorite has been reported under conditions similar to those of Dasht-e Arjan basin (2, 10).

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Table 3. Semiquantitative analysis of soil clay[†].

Soil name	Depth	Palygorskite	Smectite	Illite	Chlorite	Vermiculite	Quartz
	cm	%					
Arjan	20-64	+++	++	+	++	N	+
Sedeh	28-55	+	++	++	++	+	+
Salman	10-23	++	+++	+	+	+	+

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

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