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Diversity of Clay Minerals in the Vertisols of Three Different Climatic Regions in Western Iran

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ABSTRACT

Considerable information exists in the literature showing that expansive layer silicates are not the only clay minerals present in vertisols. However, the presence of a very high clay content dominated by fine clay, regardless of the clay type, together with the wetting and drying cycle in the soil can also produce a high shrink-swell potential. We studied some vertisols with diverse parent materials and climates from western Iran to investigate the role of parent material and climate on formation of these soils. The vertisols of Fars Province (Southwest Iran) have formed on calcareous sediments with ustic-hyperthermic soil moisture and temperature regimes and a mineralogical composition dominated by a palygorskite-chlorite suite. The vertisols of Lorestan Province (Midwest Iran) are also formed from calcareous sediments under the xeric moisture and thermic temperature regime, and contain vermiculite as the dominant clay mineral. In Kermanshah Province, vertisols have formed on limestone or in calcareous sediments. They have xeric-thermic soil moisture and temperature regimes. In Ardebil Province, vertisols are formed on volcanic sediments, and they have xeric-mesic soil moisture and temperature regimes. All vertisols, except those from Fars Province, are classical ones and include montmorillonite in the clay fraction. Our study shows that the interparticle pore size that is controlled by the size of primary particles, regardless of its nature, contributes to the shrink-swell potential in the soils we studied in Iran.

Keywords: Clay mineralogy, Interparticle pores, Iran, Palygorskite, Soil climate.

INTRODUCTION

Vertisols are soils with high shrink-swell potential, which are characterized by a high clay content, cracks that open and close periodically and wedge-shaped aggregates and/or slickensides that occur at a specific depth (Soil Survey Staff, 1999). Despite the large body of information available today, showing that smectitic clays are by far the most dominant clay minerals (Ahmad and Jones, 1969; Dixon, 1982; Dudal and Eswaran, 1988; Wilding and Tessier, 1988; Blokhuis *et al*., 1990; Buhman and Schoeman, 1995; Eswaran *et al*., 1999; Shirsath *et al*., 2000), these soils may be dominated by other minerals. According to Thomas *et al*. (2000), shrink–swell behavior can best be predicted by examining a combination of physical, chemical, and mineralogical soil properties in order to integrate them as a shrink-swell model. However, no single property accurately predicts shrink-swell potential for all soils. In fact, shrink-swell phenomena in soils and sediments cannot be explained at unit cell level, and we have to take into account also changes in the mi-

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crostructure and interparticle (interaggregate pores volume or pores between quasi-crystals) and intraparticle (pore volume organized in clay matrix or between sub-units of quasi-crystals and the interlayer space) porosity of clay minerals (Coulombe *et al.*, 1996).

Among others, Probert *et al*. (1987) in their studies of Australian vertisols have shown that kaolinite and illite are the dominant clay minerals, and smectite is either a minor fraction or is absent altogether. Yerima *et al*. (1985) and Yousif *et al*. (1988) have shown that kaolinite, with its high surface area, is the dominant clay mineral in some vertisols from El Salvador and Sudan, respectively. Mixed mineralogy has also been revealed in many studies (Allen and Fanning, 1983; Bhattacharya *et al*., 1997; Shirsath *et al*., 2000). Acquaye *et al*. (1992) found low to moderate kaolinite, vermiculite and chlorite in vertisols from Ghana. According to Coulombe *et al*. (1996), illite dominated vertisols can potentially transform into either smectite or vermiculite dominated vertisols but, on the basis of their review, no vermiculite dominated vertisols have yet been reported. Chlorite, hydroxyl interlayer vermiculite (HIV) and smectite (HIS) mixtures have also been reported in these soils, but not as dominant silicate clay mineral.

Based on an extensive review conducted by Coulombe *et al*. (1996), the fibrous clays, palygorskite and sepiolite have also been reported in vertisols from Israel, Saudi Arabia, Jordan, Iraq, Morocco, and the Canary Islands. There are several studies showing that palygorskite is rather common in many calcareous and gypsiferous soils in the clay fraction (Abtahi, 1974; Mahmoodi, 1979; Khademi and Mermut, 1999; Khormali and Abtahi, 2003); it has, however, not been proposed as a dominant clay mineral in the fraction in Iranian vertisols. The high Specific Surface Area (SSA) of palygorskite can be best responsible for its high shrink-swell properties (Ross, 1978). The porosity of clay minerals is intimately dependent on their structure which is affected by mineralogy, saturating cations, electrolyte concentration and other factors. Neaman and Singer (2000) using SEM showed that there is significant difference in arrangement of palygorskite fibers at low and high values of pH. At low pH values, closed packed domains of fibers were observed while, at high pH values, the fibers adopt a random orientation causing a higher interparticle space between. They have also shown that a 1% suspension of palygorskite exhibits a nearly Newtonian flow, similar to Na-montmorillonite suspension; and the effect of pH on its rheology is similar to that of montmorillonite. Palygorskite and smectite are intimately associated and they may transform into each other. However, the evidence for this transition in soil is scant (Singer, 1989). According to Anderson *et al*. (1973) the fine clay content and exchangeable Na^+ in usterts and torrerts in arid regions, were responsible for their high swell potential (COLE). It is worth mentioning, however, that Jeffers and Reynolds (1987) have reported the presence of expandable palygorskite in some deposites from Caspian Sea area.

The aims of this study are:

(I) To investigate the clay mineralogical composition of selected vertisols from western Iran and its effects on morphological and physico-chemical properties of the soils.

(II) To illustrate the role of climate on formation of these soils.

MATERIALS AND METHODS

The vertisols of western Iran are mainly distributed in the arid and semiarid regions of four provinces, namely: Fars with an ustic-hyperthermic soil climate, Lorestan and Kermanshah with a dry xeric-thermic one and Ardebil with a dry xeric-mesic soil climate (Figure 1). Subdivisions used for soil moisture regimes are made according to the Soil Moisture and Temperature Regimes Map of Iran (Banaei, 1998), based on Van Wambeke (2000). The parent material

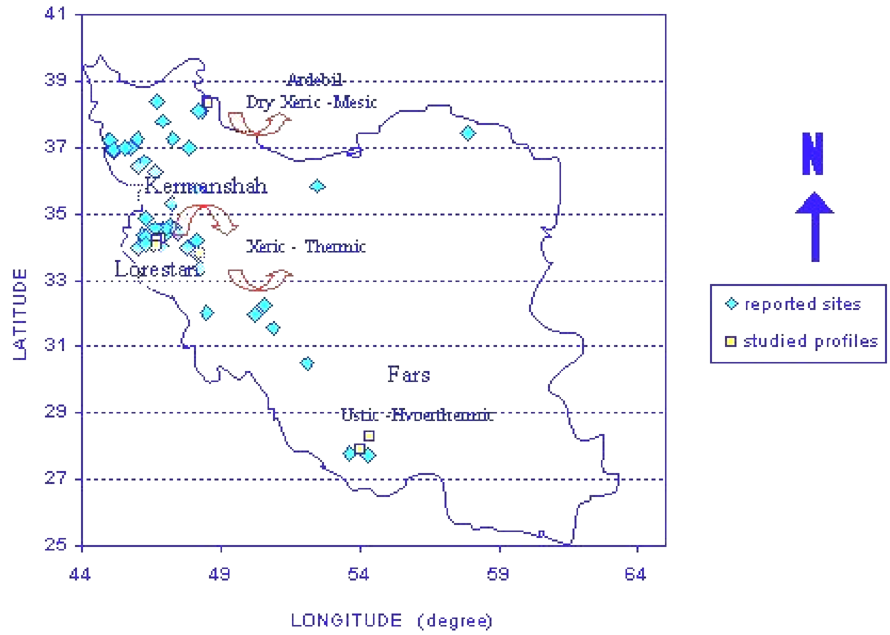

Figure 1. Vertisols and vertic subgroups in western and southern Iran (according to the Soil and Water Institute of Iran) and location of the studied profiles.

shows a relatively strong diversity among different regions. Fars Province is part of the Post-Tethyan Sea environment which is rich in evaporites (salts and gypsum) in most of its southern parts. Chronologically, the southern part of this province is formed by sedimentary rocks of Tertiary and younger (Asmari, Jahrom, Mishan and Bakhtyari) formations which are mainly composed of limestone, dolomite and marl. These sedimentary rocks contain considerable amounts of palygorskite which can be inherited into soils. However, the neoformed palygorskite has also been reported in gypsiferous soils of southern arid regions of this province (Khormali, 2003). In Lorestan Province fine calcareous sediments originated from grey thick-bedded to massive or crystallized limestone (Upper Jurassic-Lower Cretaceous) are the most dominant parent materials. In Kermanshah Province, soils on calcareous sediments in alluvial plains and on plateaux are composed of grey and brown, medium bedded to massive fossiliferous limestone and shale (Upper Cretaceous and Paleocene); and some calcareous sediments originating from dark olive-brown, low weathered siltstone and sandstone (undivided Asmari and Shahbazan) formations and blue and purple shale and marl interbedded with argillaceous limestone (Paleogene-Eocene). In Ardebil Province, volcanic rocks mainly of andesite and basalt with some volcanogenic conglomerates (Middle Eocene-Pliocene) are the main sources of parent materials.

The work was carried out in three different climatic zones of Iran as follows. (1) Fars Province with an aridic to ustic soil moisture regime (Table 1), (2) Lorestan and Kermanshah Provinces with xeric soil moisture regimes, with the highest levels of precipitation occurring mainly in Winter and Spring and almost zero in hot of Summer. These areas have relatively lower temperature and lower potential evapo-transpiration. (3) Ardebil with an intermediate level of precipitation but the most uniformly distributed over the year (Table 1).

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Table 1. General characteristics and climatic data of the regions studied.

Pro. No.	Provinces	Geographical Position		Parent material	Physiography	Climate							S.M.R[d]	S.T.R[e]
		Latitude	Longitude			M.A.T[a]	M.A.P[b]	Seasonal precipitation (mm)				ET[c]		
								Spring	Summer	Fall	Winter			
1	Fars	27° 51´	54° 23´	calcareous sed.[i]	Low land	23.1	248.0	30.5	22.1	44.4	151.0	3520	D[f].Ustic	H[g]. thermic
2	Fars	28° 16´	54° 19´	calcareous sed.[i]	Low Land	23.5	248.0	30.5	22.1	44.4	151.0	3275	Ustic	H. thermic
3	Lorestan	34° 03´	48° 07´	calcareous sed.[j]	R.A. Plain	17.2	520.2	191.6	1.4	84.6	242.6	1960	Xeric	Thermic
4	Lorestan	34° 05´	48° 06´	calcareous sed.[j]	P. Plain	17.2	520.2	191.6	1.4	84.6	242.6	1960	Xeric	Thermic
5	Kermanshah	34° 12´	46° 40´	Limestone[j]	Plateau	17.0	530.1	206.8	0.4	79.0	243.9	1980	Xeric	Thermic
6	Kermanshah	34° 03´	46° 42´	calcareous sed.[j]	R.A. Plain	17.0	530.1	206.8	0.4	79.0	243.9	1980	Xeric	Thermic
7	Ardebil	38° 18.2´	48° 32.4´	volcanic sed.[k]	R.A. Plain	8.7	311.8	116.9	33.9	87.0	74.0[h]	1315	D.Xeric	Mesic
8	Ardebil	38° 19.2´	48° 31 ´	volcanic sed.[k]	R.A. Plain	8.7	311.8	116.9	33.9	87.0	74.0[h]	1315	D.Xeric	Mesic

[a] Mean Annual Air Temperature C°; [b] Mean Annual Precipitation (mm); [c] Potential Evapotranspiration (mm); [d] Soil Moisture Regimes; [e] Soil Temperature Regimes; [f] Dry; [g] Hyper, [h] Snowfall.
[i] Miocene and Eocene - Oligocene formations rich in palygorskite.
[j] Upper Cretaceous, Lower Paleocene- Eocene, Middle Eocene, Upper Eocene-Miocene and Pliocene formations.
[k] From igneous rocks with some limestone.

The mineralogical composition of these soils is determined following the description and routine analysis of fifty-five pedons (Heidari, 2004); results from the selected eight profiles with more distinctive vertic properties are presented in Tables 1 and 2. Particle size distribution was determined using the hydrometer procedure (Gee and Bauder, 1986), and the carbonate content was determined through calcimetry (Salinity Laboratory Staff, 1954). Electrolytic conductivity (EC) and pH were determined for saturated extracts (Salinity Laboratory Staff, 1954). The CEC of soils and clays (using about 1g clay) were determined using Na-acetate at pH 8.2 (Chapman, 1965). The ratio of fine clay to total clay was determined by centrifugation (Whittig and Allardice, 1986), after separation of the clay by settling. The coefficient of linear extensibility (COLE) was determined on soil pastes (Schafer and Singer, 1976).

The composition of clay fractions (coarse and fine) was determined using a Siemens XRD Model D5000 with K_α radiation, after Mg-saturation, Mg-saturation and glycerol solvation, K-saturation, and K-saturation followed by heating to 550°C. Pre-treatments were carried out following the procedures of Kunze and Dixon (1986). Some samples were HCl treated, in order to differentiate chlorite from kaolinite (Moore and Reynolds, 1989). Scanning Electron Microscopy (SEM), JEOL 6400, and transmission electron microscopy (TEM) LEO 906E were also used for the further characterization and qualitative determination of fibrous clays according to fiber frequency.

RESULTS

Fars Province

Table 1 shows general characteristics and climatic data of the regions studied. The considerably higher potential evapotranspiration in this area, together with some Summer rain, causes more frequent wetting and drying than in the other regions studied, and the development of prominent vertic features, such as slickensides, wedge-shaped aggregates and deeper cracks (Table 2).

Morphology and Physico-chemical Data

The soils are very deep (>130 cm), with an ochric epipedon at the surface. Morphological characteristics of the studied profiles are given in Table 2. The cracks are narrower but closer and deeper, compared with the soils in other regions. Irregular fine to medium carbonate nodules (3-5 %) and mottling (fine to medium, 2 %) occur at a lower depth in several profiles. Round gilgai with a maximum height of 15 cm has been observed on the undisturbed areas of some pedons (for example, on pedon no. 2).

The clay content is high throughout the pedons (49 to 85.6%), with the highest amounts in the subsurface horizons (Table 2). The ratios of fine to total clay are generally high and usually highest in the B_{ss} horizons (0.48 to 0.77). The coefficient of linear extensibility (COLE) varies between 0.06 and 0.11. The pH values are always in the alkaline range (7.1-7.9), as a result of the equilibration of high calcium carbonate content (25.2-38.7%) and usually high soluble salts of sodium (EC, 3.9-24.4 dS m^{-1} and SAR of saturated extract up to 41.88). The CECs of the soils are very low (7.77-11.1 $cmol_c\ kg^{-1}$) and the clay CECs are low to medium (25.46-44.56 $cmol_c\ kg^{-1}$). Due to using the hydrometer method for soil texture analysis, the clay fractions probably contain carbonates.

Mineralogical Data

The fine and total clay fractions are dominated by palygorskite and chlorite. Illite and kaolinite are accessory phases in the coarse clay fraction (Figure 2) and (Table 3). Relatively sharp and distinct 10.4 Å peaks, together with lower intensities 6.4 Å peaks which are resistant in all treatments (Figure 2) together with TEM micrographs

Table 2. Classification and physico-chemical properties of the soils studied.

Horizon[a]	Depth (cm)	Structure[b]	Particle size (%) clay	silt	sand	pH_e	EC_e (dSm^{-1})	$CaCO_3$ (%)	OC (%)	CEC ($cmol_c kg^{-1}$) CEC_s[c]	CEC_c[d]	FC/TC[e]	COLE[f]	Cracks width cm
1. Aridic Haplustert (Fars)														
A_p	0-17	m2sabk	53.0	36.0	11.0	7.9	7.44	34.4	0.68	7.77	nd[g]	nd	0.09	2.5
AB	17-38	m2sabk	57.0	33.8	9.2	7.5	5.8	33.4	0.63	7.89	33.69	0.66	0.11	1.5
B_{ss1}	38-55	m3pr	55.0	35.6	9.4	7.6	6.4	35.0	0.39	7.79	35.20	0.59	0.09	1.5
B_{ss2}	55-75	m3pr	55.0	34	11	7.5	6.15	37.4	0.44	7.77	nd	nd	0.11	0.5
B_{ss3}	75-110	m3pr	53.0	39.6	7.4	7.3	8.9	37.1	0.44	7.77	37.18	0.77	0.08	
B_{ss4}	110-130	m3pr	49.0	41.6	9.4	7.3	6.6	38.7	0.39	7.77	39.29	0.74	0.10	
2. Halic Haplustert (Fars)														
A_1	0-10	f2sabk	75.0	20.0	5.0	7.2	3.9	27.3	0.54	10.51	26.59	0.51	0.08	3.5
A_2	10-23	m2abk	75.0	19.6	5.4	7.4	5.6	28.0	0.44	10.51	nd	0.48	0.07	3
AB	23-45	m3pr	85.6	11.2	3.2	7.4	8.2	26.0	0.44	11.10	nd	0.53	0.08	2
B_{ss1}	45-60	c3pr	85.6	10.8	3.6	7.3	9.6	26.6	0.39	9.93	nd	nd	0.09	1
B_{ss2}	60-80	c3pr	81.6	11.2	7.2	7.2	13.0	25.2	0.49	10.51	25.46	0.64	0.09	0.5
B_{ss3}	80-110	c3pr	77.6	10.8	11.6	7.1	24.4	25.3	0.44	9.36	nd	0.55	0.06	
B_{ss4}	110-150	c3pr	81.6	11.2	7.2	7.2	18.1	26.6	0.44	10.51	44.56	0.68	0.10	
3. Chromic Calcixeret (Lorestan)														
A_p	0-26	f2gr	53.6	30.8	15.6	7.8	0.8	13.6	1.22	28.27	nd	nd	nd	10
B_{ss1}	26-48	m3pr	61.6	27.2	11.2	7.9	0.4	13.0	0.88	27.32	nd	nd	nd	5
B_{ss2}	48-63	m3pr	59.6	27.6	12.8	7.9	0.4	13.1	0.68	27.32	53.51	0.62	0.16	3
B_{kss1}	63-87	m3pr	60.0	23.2	16.8	7.8	1.2	13.1	0.68	29.24	nd	nd	nd	3
B_{kss2}	87-110	m3pr	56.0	32	12.0	7.9	0.3	12.4	0.63	30.22	45.68	0.67	0.20	2
B_{kss3}	110-140	m3pr	51.6	32.4	16.0	7.8	0.5	20.7	0.39	18.71	nd	nd	nd	2
4. Chromic Calcixeret (Lorestan)														
A_{p1}	0-12	f2gr	53.6	38.8	7.6	7.5	1.29	7.4	0.93	21.96	nd	nd	nd	5
A_{p2}	12-26	f2pr	59.2	32.4	8.4	7.7	0.3	11.7	0.97	19.50	48.56	0.51	0.14	1.5
B_{ss1}	26-45	m3pr	63.6	28.4	8.0	7.6	0.3	13.1	0.73	21.96	49.73	0.47	0.15	1
B_{ss2}	45-70	m3pr	63.6	28.4	8.0	7.8	0.3	13.8	0.58	21.96	49.83	0.45	0.14	0.5
B_{ss3}	70-90	m3pr	60.0	32	8.0	7.8	0.3	14.3	0.44	21.96	56.24	0.74	0.15	0.3
B_{kss1}	90-110	m3pr	61.6	30.8	7.6	7.6	0.5	15.1	0.58	24.57	48.43	0.69	nd	
B_{kss2}	110-140	m3pr	59.2	32.0	8.8	7.6	1.3	18.1	0.44	21.69	46.24	0.47	0.17	
5. Chromic Calcixerert (Kermanshah)														
A_p	0-20	m2gr	58.4	32.4	9.2	7.9	0.4	27.9	1.39	22.82	48.8	0.53	0.12	4
B_{ss}	20-44	c3pr	56.8	34.0	9.2	8.0	0.3	28.3	1.01	24.57	41.57	0.47	0.11	2
B_{kss1}	44-65	c3pr	67.2	24.8	8.0	7.7	0.3	32.4	1.02	21.96	nd	nd	nd	0.5
B_{kss2}	65-100	c2pr	73.2	24.8	2.0	7.6	0.3	35.7	1.23	21.96	60.32	0.73	0.14	
B_{kss3}	100-155	c2abk	79.2	18.8	2.0	7.7	0.5	39.9	1.13	21.96	58.35	0.67	0.14	
B_{kss4}	155-175	c1abk	72.6	24.4	3.0	7.6	0.2	43.0	0.7	19.50	52.97	0.77	0.13	
6. Chromic Haploxerert (Kermanshah)														
A_p	0-20	m2gr	54.4	30.4	15.2	8.2	0.7	20.5	1.18	21.96	48.38	0.36	0.12	7
B_{ss1}	20-49	m3pr	63.2	24.4	12.4	8.2	0.4	21.8	0.59	23.68	nd	nd	nd	4
B_{ss2}	49-80	m3pr	60.8	26.0	13.2	8.2	1.1	21.4	0.54	21.13	38.46	0.42	0.14	1
B_{ss3}	80-110	m3pr	65.2	19.6	15.2	7.6	7.7	18.4	0.54	25.57	43.81	0.35	0.10	
B_{ss4}	110-150	m3pr	64.8	18.0	17.2	7.6	7.7	18.3	0.38	29.24	nd	nd	nd	
7-Typic Calcixerert (Ardebil)														
A_p	0-23	m2gr	44.0	34.0	22.0	7.7	1.3	0.0	1.01	31.22	nd	nd	nd	3
AB_{ss}	23-40	f2abk	44.0	32.0	24.0	7.8	1.0	0.0	0.91	33.26	nd	0.85	nd	2
B_{tss}	40-60	f2pr	32.0	28.4	39.6	8.5	1.6	0.0	0.48	28.27	53.86	0.71	0.07	1
$2B_{tkb}$	60-90	m2pr	20.0	10.8	69.2	8.3	1.2	12.7	0.24	19.50	57.46	0.85	0.05	
$3B_{kssb1}$	90-125	m3pr	48.0	28.0	24.0	8.3	0.8	12.4	1.01	35.37	66.42	nd	0.17	
$3B_{kssb2}$	125-165	c3pr	62.0	20.0	18.0	7.8	1.4	14.9	0.43	34.3	nd	0.76	nd	
$3B_{kssb3}$	165-200	m3pr	68.0	20.0	12.0	8.2	1.5	25.1	0.05	24.57	nd	nd	nd	
8-Typic Haploxererert (Ardebil)														
Ap	0-25	m3gr	52.8	30.8	16.4	8.0	1.1	0.0	2.36	39.78	78.40	nd	0.14	4
Bss1	25-50	c3pr	56.8	22.8	20.4	8.0	0.6	0.0	1.49	38.65	nd	0.82	nd	2
Bss2	50-90	c3pr	nd	nd	nd	8.0	0.5	0.0	1.39	40.92	57.61	nd	0.21	0.5
Bss3	90-140	c3pr	35.6	24.4	40.0	8.3	0.3	0.0	0.29	26.39	nd	0.73	nd	
Bss4	140-170	c3pr	32.8	17.6	49.6	7.8	1.0	0.0	0.34	20.31	nd	0.79	nd	
C	170-200	mas-	16.8	5.6	77.6	7.9	0.6	0.0	0.24	13.64	nd	nd	nd	

[a] p= Tillage or other disturbance; ss= Slickenside; k= Accumulation of carbonates; t= Accumulation of silicate clays, b= Buried.
[b] According to Soil Survey Staff (1993). f= Fine; m= Medium; c= Coarse; 1= Weakly developed; 2= Moderately developed; 3= Strongly developed; abk= Angular blocky; sabk= Sub angular blocky; pr= Prismatic; gr= Granular, single gr.= Single grain.
[c] CECs= CEC of soil; [d] CECc= CEC of clay fraction; [e] FC/TC= Fine clay over total clay; [f] Coefficient of linear extensibility, [g] Not Determined.

Table 3. Mineralogical composition of clay fraction in the soils used in this study.

Profile No.	Horizon	Depth (cm)	Fraction	Mineralogy[a]
1 (Fars)	AB	17-38	Total clay	Pal.>Chl.>Ill.>Kao. >Smec
	B_{ss1}	38-55	Total clay	Pal.>Chl.>Ill.>Kao. >Smec
	B_{ss3}	75-110	Total clay	Pal.>Chl.>Ill.>Kao. >Smec
	B_{ss4}	110-130	Total clay	Pal.>Chl.>Ill.>Kao. >Smec
2 (Fars)	A_1	0-10	Total clay	Pal.>Chl.>Ill.>Kao. >Smec
	A_2	10-23	Fine clay	Pal.>Chl. >Smec
			Coarse clay	Chl.>Pal.>Ill.>Kao. >Smec
	AB	23-45	Fine clay	Pal.>Chl. >Smec
			Coarse clay	Chl.>Pal.>Ill.>Kao. >Smec
	B_{ss1}	45-60	Fine clay	Pal.>Chl. >Smec
			Coarse clay	Chl.>Pal.>Ill.>Kao. >Smec
	B_{ss2}	60-80	Total clay	Pal.>Chl.>Ill.>Kao. >Smec
	B_{ss3}	80-110	Fine clay	Pal.>Chl. >Smec
			Coarse clay	Chl.>Ill.>Pal.>Kao. >Smec
	B_{ss4}	110-150	Total clay	Pal.>Chl.>Ill.>Kao. >Smec
3 (Lorestan)	B_{ss2}	48-63	Total clay	Smec.>Ver.>Ill.> Kao.
	B_{kss2}	87-110	Total clay	Ver.> Smec.> Ill.> Kao.
4 (Lorestan)	A_{p2}	12-26	Total clay	Smec.>Ver.>Ill.> Kao.
	B_{ss1}	26-45	Total clay	Ver.>Smec.> Ill.>Chl.> Kao.
	B_{ss2}	45-70	Total clay	Ver..> Ill. > Smec.> Chl.> Kao.
	B_{ss3}	70-90	Total clay	Ver..> Ill. > Smec.> Chl.> Kao.
	B_{kss1}	90-110	Total clay	Ver..> Ill. > Smec.> Chl.> Kao.
	B_{kss2}	110-140	Total clay	Ver..> Ill. > Smec.> Chl.> Kao.
5 (Kermanshah)	A_p	0-20	Total clay	Smec.> Chl.> Ill.> Kao.
	B_{ss}	20-44	Total clay	Smec.> Chl.> Ill.> Kao.
	B_{kss2}	65-100	Total clay	Smec.> Chl.> Ill.> Kao.
	B_{kss3}	100-155	Total clay	Smec.> Chl.> Ill.> Kao.
	B_{kss4}	155-175	Total clay	Smec.> Chl.> Ill.> Kao.
6 (Kermanshah)	A_p	0-20	Total clay	Smec.> Chl.> Ill.> Kao.
	B_{ss2}	49-80	Total clay	Smec.> Chl.> Ill.> Kao.
	B_{ss3}	80-110	Total clay	Smec.>> Ill.
7 (Ardebil)	B_{tss}	40-60	Total clay	Smec.>>> Ill.>Kao.
	$2B_{tk}$	60-90	Total clay	Smec.>>Ill.>Kao.
	$3B_{kssb1}$	90-125	Fine clay	Smec.
			Coarse clay	Smec.>>Ver.>Ill.>Kao.
8 (Ardebil)	A_p	0-25	Fine clay	Smec.
			Coarse clay	Smec.>>Ver.>Ill.>Kao.
	B_{ss2}	50-90	Fine clay	Smec.
			Coarse clay	Smec.>>Ver.> Ill.> Chl.>Kao.
	C	170-200	Fine clay	Smec.
			Coarse clay	Smec.>>Ver.> Ill.> Chl.>Kao.

[a] Pal.= Palygorskite; Chl.= Chlorite; Ill.= Illite; Kao.= Kaolinite; Ver.= Vermiculite, Smec.= Smectite.

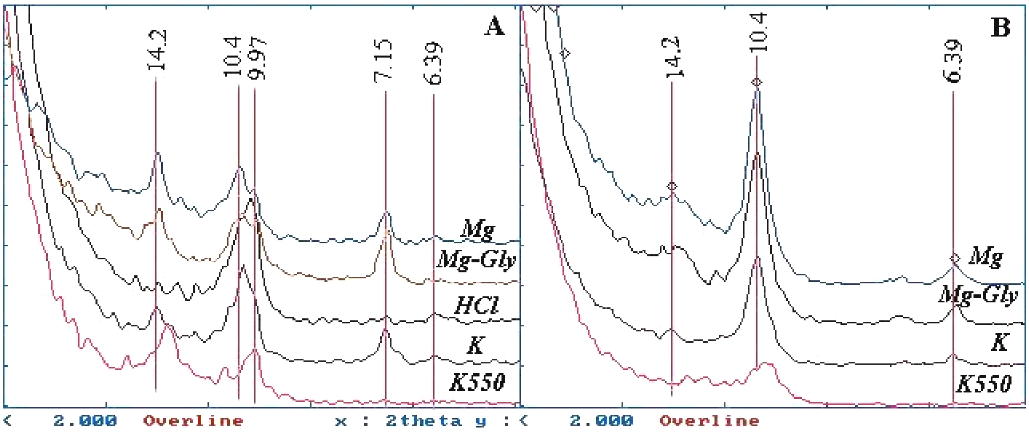

Figure 2. X- ray diffractograms of clay fractions in Fars Province, (A) total clay, AB horizon, pedon No. 1, (B) fine clay, B_{ss1} horizon, pedon no. 2.

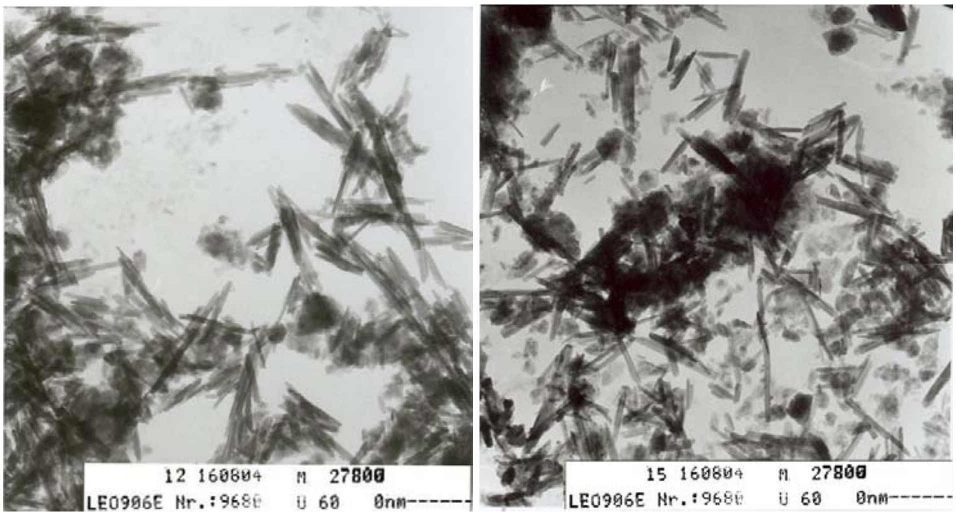

Figure 3. Transmition Electron Microscopy (TEM) confirms the existence of fibrous palygorskite. Fine clay fraction B_{ss1} horizon of pedon No. 2 (left) and total clay fraction (right) from Fars Province**.**

(Figure 3), show the predominance of palygorskite over the other clay minerals. Also, the sharp and distinct 14.2 Å peak that does not change with Mg-Gly treatment but disappears on HCl treatment suggests the presence of chlorite in this area. However, the relative intensities of 10.4 Å, and 6.4 Å compared with 14.2 Å peaks is greatly intensified in the fine clay fraction (Figure 2-B), indicating the concentration of fibrous palygorskite in this fraction. Transmission Electron Microscopy has also confirmed these results (Figure 3). Nevertheless, a few fine irregular and cloudy particles on TEMs, particularly on fine clays (Figure 3 left), together with the increase of the 14.2 Å peak intensity after glycerol solvation of Mg-saturated samples, along with the appearance of a small 17-18 Å peak on Mg-glycerol treated samples (Figure 2), are all indications of a low amount of smectite on clay mineral suites, particularly in the fine clay fraction in these soils.

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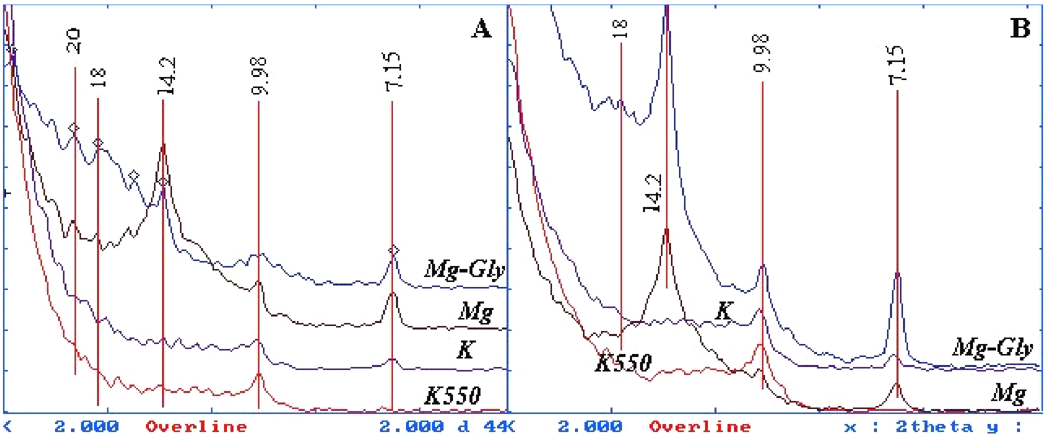

Figure 4. X- Ray diffractograms of the total clay in the Lorestan, pedon No. 3, (A), B_{ss2} horizon, and (B), B_{kss2} horizon.

Lorestan and Kermanshah

These soils are characterized by xeric and thermic soil moisture and temperature regimes (Table 1). Mean annual precipitation is relatively higher and Summer rain is almost nil (<1%) but potential evapotranspiration is much lower than in Fars Province.

Morphology and Physico-chemical Data

These soils are very deep with an ochric or sometimes mollic epipedon in the surface horizons (Table 2). Subsurface horizons show a moderately to strongly developed, medium to coarse prismatic structure with slickensides and wedge-shaped aggregates, grading to angular blocky in the lower part of some profiles. These structures have been observed at lower depths than in the dryer vertisols of Fars Province.

Most of the pedons have been observed show moderate to strongly developed calcic horizons which are usually overlain by a cambic horizon. Cracks extend to the depth of 50 cm in the profiles; with about 2 to 10 cm of width at the surface, and 1 cm or more at a depth of 50 cm.

The clay content is high throughout the profiles (51.6 to 79.2%), with higher values in the subsurface horizons (Table 2). The ratios of fine to total clay are between 0.35 and 0.77. The higher values usually occur in the lower B_{ss} horizons (Table 2). The coefficient of linear extensibility (COLE) is quite high (0.10 and 0.20). The pH values are nearly neutral and slightly alkaline (7.4 and 8.2) and the electrical conductivity of saturated extracts range between 0.21-7.7 dS m^{-1}. The soil CEC changes between 18.71 and 30.22 $cmol_c$ kg^{-1}, and is as high as that of the Fars Province (Table 2). This is mainly due to difference in clay types. The EC is also lower, except in the subsoil of the Chromic Haploxererts of Kermanshah. The clay CECs are also higher than in the soils from Fars Province (41.6 – 60.3 $cmol_c$ kg^{-1}).

Mineralogical Data

The clay fraction of the profiles from Lorestan is dominated by smectite and vermiculite, with illite, chlorite and kaolinite as accessory silicate minerals (Figure 4 and Table 3). In Figure 4A, the sharp and high 14 Å peak in the Mg-saturated treatment which has mostly expanded after glycerol solvation, is an indication of a high amount of smectite. The broad 14 Å peak is a likely the indication for small-sized mineral particles (Coulombe *et al*., 1996). However, the presence of a sharp and intensive 14 Å peak in the Mg-saturated sample (Figure 4B) and little expansion in the glycerol solvated samples and its collapsing after K saturation are interpreted as showing the presence of a high amount of vermiculites in these samples.

From the XRD results, we can conclude that the pedons from Kermanshah Province are dominated by smectite, with different amounts of vermiculite, illite, chlorite, and kaolinite (Figure 5 and Table 3). Figure 5 shows the X-ray diffractograms of clay fractions of pedon 6 in Kermanshah Province. The intensive 14 Å peaks in Mg-saturated samples are dominated by expanding clays in surface and subsurface horizons (Figures 5A and B).

Ardebil Region

The soils of this region are derived both from volcanic materials and carbonatic sediments with annual precipitation, noticeably lower than the Lorestan and Kermanshah regions. The precipitation has two specific characteristics: (1) a relatively regular distribution pattern throughout the year and (2) the amount of snowfall is highest in this area. The potential evapo-transpiration is still three to four times as high as the precipitation (Table 1).

Morphological and Physico-chemical Data

The studied pedons are very deep and most of them have mollic epipedons with color values of 3 and chromas of 2 or 1 and high organic carbon contents (Table 2); the structure of the surface horizons is fine to medium granular (Table 2). The subsurface horizon is mainly moderately to strongly developed, fine to medium wedge-shaped peds and angular blocky, with slickensides similar to those from humid regions. Crack widths are 3 to 4 cm at the surface and have a width of 1 cm or more at a depth of 50 cm. Irregular medium carbonate nodules have been observed in the subsurface horizons.

The clay content is between 16.8 to 68%, but it is always > 30% in the top 50 cm (Table 2). However, the ratio of fine to total clay is the highest among the soils studied (0.71 to 0.85). The coefficient of linear extensibility (COLE) is also quite variable (0.02-0.2) due to the variable amounts of clays. The pH values are somewhat higher (8.0-8.5) in comparison with the soils from the other regions. There is no carbonate at the surface and only some in the subsoil of Ardebil, giving a Typic Calcixererts profile. EC values are low (0.3-1.6 dS m^{-1}). The soil CECs are variable (13.6-40.9 $cmol_c$ kg^{-1}) whereas clay CECs varying between 53.9 and 78.4 $cmol_c$ kg^{-1} are the highest compared

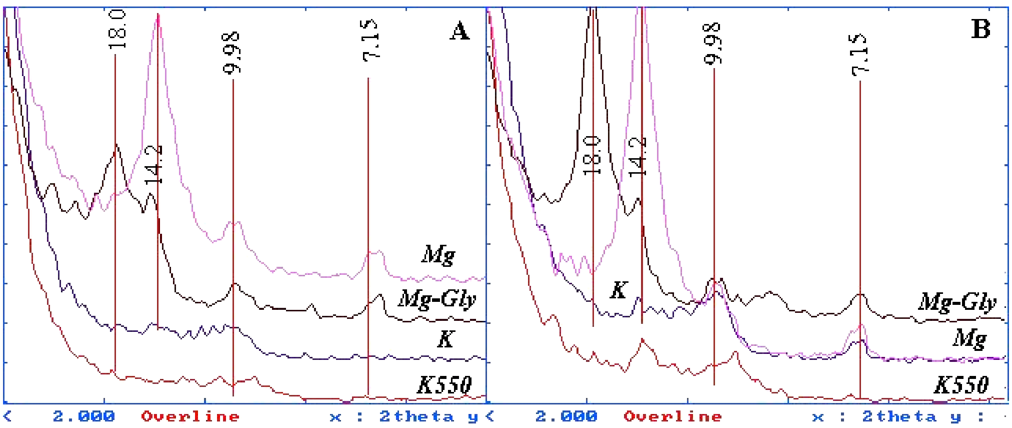

Figure 5. X- Ray diffractograms of total clay in pedon No. 6, A: A_p horizon, and B: B_{ss2} horizon.

with the soils in the other two climatic regions.

Mineralogical Data

Smectite is by far the most dominant silicate clay mineral in the fine and coarse clay fractions. Illite, vermiculite and kaolinite are recognized as accessory minerals (Figure 6 and Table 3). The fine clay fraction is almost entirely composed of smectite (Figure 6). The broadened character of the 14 Å peaks may also indicate the fineness of the smectitic clays (Dixon, 1986).

DISCUSSION

Morphological properties are the most important characteristics for distinguishing vertisols from the soils of other orders (Mermut *et al*., 1996). All the soils studied exhibit all the required morphological characteristics, including high clay content, slickensides or a wedge-shaped structure at specific depths and cracks that periodically open and close. Some soils exhibit a distinct gilgai micro topography and granular micro aggregates at the surface.

The soils of Fars Province experience more frequent wetting and drying compared to the somewhat humid and cooler vertisols of Lorestan, Kermanshah, and Ardebil Provinces. They have slickensides and cracks although very little smectites are found in their clay fractions. The typical vertisol morphology is probably due to the fineness of the clay fraction coupled with the influence of climatic regime. The soils of the Fars Province are under ustic-hyperthermic regimes.

Almost 60% of the world's vertisols have an ustic moisture regime (Soil Survey Staff, 1999). This shows the importance of climate in vertisols formation. The other decisive factor in the genesis of vertisols is their parent material, including clay mineralogy. With enough clay content (i.e.>30%), according to Ahmad (1983) and Smith *et al*. (1985), maximum swelling is achieved when a soil undergoes the maximum change from dry to wet conditions. Hence, the drier a vertisol is prior to re-wetting, the greater the internal swelling pressure will be. Also, the more rapid the desiccation and the greater the frequency of wet/dry events, the greater will be the structure development.

The vertisols of Fars Province experience a hyperthermic temperature regime and, hence, they will undergo intensive desiccation. However, at the same time, since the soil moisture control section is not permanently dry in warm seasons and almost 40% of the total rain occurs during Spring, Summer and Autumn (Table 1), the soils will be

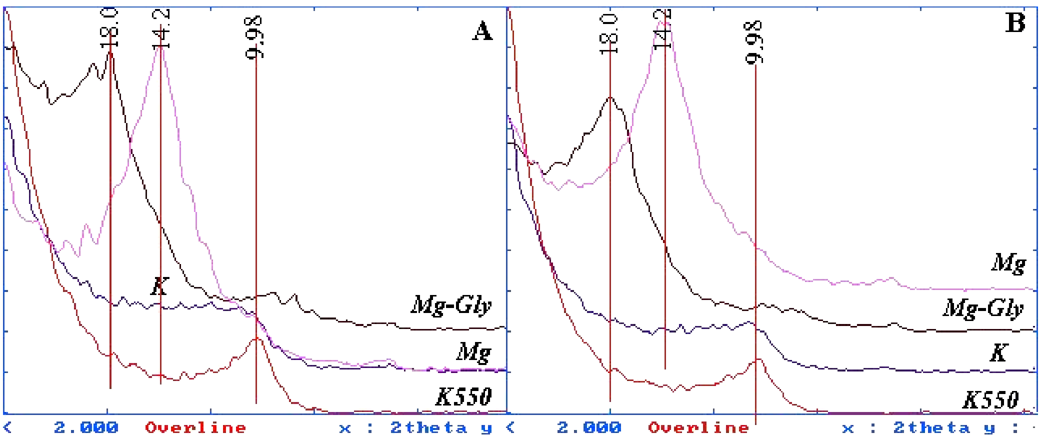

Figure 6. X- ray diffractograms of the fine clay fraction in the pedon No. 8, A: A_p horizon, and B: B_{ss2} horizon.

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re-wetted more frequently compared with those of the Kermanshah and Lorestan or cooler Ardebil regions (Table 1). Morphologically speaking, the dry vertisols of Fars Province show clear differences from those of more humid and cooler vertisols of Kermanshah, Lorestan and Ardebil Provinces in terms of the depth of slickenside formation. In the vertisols of Fars Province, slickensides (B_{ss} horizon) usually occur in lower parts of the profile (38-45 cm), whereas, in vertisols from more humid and cooler regions, these occur at a relatively shallower depth (20-26 cm). This is in contradiction with the findings of Vadivelu and Challa (1985) who suggested that the higher the rainfall, the deeper the slickenside formation will be and a deeper B_{ss} horizon will form. Yaalon and Kalmar's (1978) conclusion that slickensides usually develop at the bottom of cracks verifies the results obtained in this study observing cracks that extend to a greater depth in Fars Province.

The other visible difference between the dry vertisols of Fars Province and the more humid vertisols of other regions is their surface structure. The structure of vertisols in Fars Province is mostly angular-subangular blocky and crusty in cultivated and uncultivated soils, respectively, whereas it is predominantly granular in vertisols in more humid regions (Table 2). This structure is believed to be the most striking visual aspect of vertisol morphology (Blokhuis, 1982). The type and degree of structural development provides information about the soil genesis and agricultural management potential of these soils (McGarry, 1996). Many studies have shown a good relationship between clay content, fine clay/total clay ratio, clay mineralogy and other factors on one side, and type and degree of soil structure development on the other (De Vos and Virgo, 1969; Newman, 1983; Little *et al*., 1992). Other studies emphasize that climatic influences are of more importance for structure development (Ahmad, 1983; Smith *et al*., 1985). Therefore, the driest vertisols of Fars Province, Aridic Haplusterts (with 49-57% clay) and Halic Haplusterts (with 75-86 % clay) both exhibit an angular blocky surface structure.

The vertisols found in more humid and cooler climates, mostly with lower clay content (44-59%) are usually characterized by a surface granular (mulch) microstructure (Table 2). It is, therefore, believed that the low CEC, high amounts of palygorskite (especially in fine clay fraction) and higher interparticle spaces resulting from packing of its fibers, together with the predominant effect of climate, must have played an important role in the genesis of the soil structure in dry vertisols from Fars Province. This effect has also been documented by many other authors (De Vos and Virgo, 1969; Ahmad, 1983; Smith *et al*., 1985; Mermut *et al*., 1996). Probert *et al*. (1987) have indicated that the thin surface crust in vertisols is related to their lower CEC and the predominance of Mg^{++} and Ca^{++} ions with a considerable amount of exchangable and soluble Na^{+} in the surface soils. According to McGarry (1996) self mulching of Australian vertisols is related to high CECs and low exchangeable Na^{+} while the presence of Na^{+} at or near the soil surface, even in low amounts, is responsible for crust formation due to its effect on soil dispersion and disturbance of the structure. Therefore, moderate EC (Table 2) and low SAR (3-6) (Heidari, 2004) and CEC values at the surface may explain the surface crusting in the vertisols of Fars Province.

The dominant clay mineralogy of the vertisols from the Fars area (palygorskite and chlorite) as confirmed by XRD studies (Figure 2), TEM (Figure 3) and clay CEC (Table 2) is probably mostly inherited from the parent material (Abtahi, 1974). This may suggest the formation of vertisols in which the clays have not had enough time to transform into smectite.

The high amounts of fine clay and very high fine clay/total clay ratios, especially in the B_{ss} horizons (Table 2), and the relatively high level of sodium ion are likely to create conditions for high shrink-swell potential. There are a number of studies showing that the shrink-swell phenomenon could also be influenced by many other parameters. These include the interlayer spacing of phyllosilicates, the thickness of the diffuse double layer and interparticle porosity, which are not solely related to the type of clays (Allen and Fanning, 1983; Yerima *et al*., 1985; Yousif *et al*., 1988; Aquaye *et al*., 1992; Coulombe *et al*., 1996; Bhattacharyya *et al*., 1997; and Shirsath *et al*., 2000).

Vertisols from the relatively humid regions of Kermanshah and Lorestan and the less humid and cooler Ardebil region all exhibit the normal characteristics of vertisols. The clay mineralogy of these soils is generally smectite (Table 3). However, the presence of high amounts of vermiculite in some samples of vertisols from Lorestan is rather unusual. Based on an extensive review of Coulombe *et al*. (1996), we can say that vermiculite is a common component in vertisols, but usually in minor amounts. Mica-rich parent materials are thought to be transformed either into vermiculite or smectite, depending on environmental conditions. The parent materials of vertisols from Lorestan and Kermanshah Provinces are mainly calcareous and those from Ardebil are calcareous and/or volcanic sediments. Mica is omnipresent in these soils as is indicated in mineralogical analyses (Heidari *et al.,* 2005). However, since vermiculite-rich vertisols have only been observed in Lorestan, it could either be inherited clay from the sedimentary parent materials or have both a geogenic and pedogenic origin. Yet, a depth function distribution pattern has not been observed, although these soils show pedogenically carbonate accumulated horizons (Heidari, 2004).

CONCLUSIONS

The type and degree of structure development provides information about soil genesis and other properties. In vertisols, structure - the most striking aspect of soil morphology- is normally correlated with a high proportion of expansive clays, particularly montmorillonite and periodically dry and moist seasons. The present results indicate that the wedge-shaped structure and/or slickensides have been moderately to strongly developed in three different climatic regions in Iran, although in quite variable suites of silicate clays. The vertisols from the driest climatic province of Fars (Southwest Iran) have palygorskite as the main clay mineral, particularly in fine clay, with little smectite. These soils are characterized by rather narrow (1.5- 3.5 cm) but deep (38-45 cm) cracks in a dense pattern (with about 20 cm mutual distance), which is believed to be the result of relatively more frequent wet and dry cycles and a very strong desiccation phenomenon, caused by a rather high temperature (hyperthermic) and rain distribution pattern (ustic). A high clay content, mainly fine clay, dominated by randomly oriented fibers of palygorskite conditioned by relatively high pH, and presumably plenty of interparticle spaces, together with many cycles of strong desiccation and re-wetting, are considered to be responsible for the genesis of these typical vertisols that show all the required characteristics, as well as the typical sink hole and model gilgai microtopography. Vertisols from the most humid regions of Kermanshah and Lorestan and the cooler and dryer province of Ardebil are mostly comparable with classic vertisols and are dominated by smectite silicate clays. In these soils, the cracks are fewer but wider (2-10 cm) and much shallower compared with the vertisols of the drier region of Fars Province. However, in some vertisols from the most humid region of Lorestan, vermiculite was found to be the dominant clay and smectite occurred as a secondary phase. This finding also seems to be rather rare or even exceptional. Yet, in these soils, smectite is still an important component of silicate clays, and can significantly influence their behavior and their formation.

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REFERENCES

1. Abtahi, A., 1974. Contribution to the Knowledge of the Soils of Shiraz Area (IRAN), Ph.D. Thesis. State University. Ghent, Belgium.
2. Acquaye, D. K., Dowuona, G. N., Mermut, A. R. and Arnaud, St. R. J., 1992. Micromorphology and Mineralogy of Cracking Soils from the Accra Plains of Ghana. *Soil Sci. Soc. Am. J.*, **56**: 193-201.
3. Ahmad, N., 1983. Vertisols. In: "*Pedogenesis and Soil Taxonomy, Vol. 11, the Soil Orders*". Wilding, L. P., Smeck, N. E. and Hall G. F. (Eds.), Elsevier, Amsterdam, pp. 91-123.
4. Ahmad, N., and Jones, T. L., 1969. Genesis, Chemical Properties, and Mineralogy of Caribbean Grumusols. *Soil Sci*., **107**:166-174.
5. Ahmad, N. and Mermut, A. R., 1996. Vertisols and Technologies for Their Managements. Developments in *Soil Science* No.24. Elsevier Publ. Netherlands.
6. Allen, B. L. and Fanning, D. S. 1983. Composition and Soil Genesis. In: "*Pedogenesis and soil taxonomy. I. Concepts and Interactions*". Wilding, L. P., Smeck, N. E. and Hall, G.F. (Eds.), Amsterdam, Elsevier. pp. 141-192.
7. Anderson, J. U., Elfadil Fadul, K. and O'Connor, G. A. 1973. Factors Affecting the Coefficient of Linear Extensibility in Vertisols. *Soil Sci. Soc. Am. Proc.*, **37**: 298-299.
8. Banaei, M. H. 1998. *Soil Moisture and Temperature Regimes Map of Iran*. Soil and Water Institute, Tehran, Iran.
9. Bhattacharyya, T., Pal, D. K. and Deshpande, S. B., 1997. On Kaolinitic and Mixed Mineralogy Classes of Shrink-swell Soils. *Aust. J. Soil Res*., **35**: 1245-1252.
10. Blokhuis, W. A.. 1982. Morphology and Genesis of Vertisols. In: *Vertisols and Rice Soils of the Tropics*. Trans. 12th Inter. *Congr. Soil Sci.*, New Dehli, **3**: 23-47.
11. Blokhuis, W. A., Kooistra, M. J. and Wilding, L. P. 1990. Micromorphology of Cracking Clay Soils (Vertisols), In: "*Soil Micromorphology: A Basic and Applied Science*". Douglas, L. A. (Ed.), Developments in Soil Science 19. Elsevier, Amsterdam. pp. 123-148.
12. Buhman, C. and Schoeman, J. L. 1995. A Mineralogical Characterization of Vertisols from the Northern Regions of the Republic of South Africa. *Geoderma*., **66**: 239-257.
13. Chapman, H. D. 1965. Cation Exchange Capacity. In: "*Methods of Soil Analysis, Part 2, Chemical and microbiological properties*". Black, C. A. (Ed.) Agronomy Monograph No. 9. American Society of Agronomy, Madison, Wisconsin. pp. 891-900,
14. Coulombe, C. E., Dixon, J. B. and Wilding, L. P. 1996. Mineralogy and Chemistry of Vertisols. In: "*Vertisols and Technologies for their Managements*". Ahmad N. and Mermut, A. R. (Eds), Developments in Soil Science No.24. Elsevier Publ. Netherlands. pp. 115-200.
15. De Vos, J. H. and Virgo, K. J. 1969. Soil Structure in Vertisols of the Blue Nile Clay Plains. *J. Soil Sci.*, **20**: 189-206.
16. Dixon, J. B., 1982. Mineralogy of Vertisols. In: "*Vertisols and rice soils of the Tropics*", Symposia papers II. 12th ICSS, New Dehli (India). pp. 48-59.
17. Dixon, J. B, Weed, S. B. and Kittrick, J. A. 1986. *Minerals in Soil Environment*.2nd ed. SSSA Book Series No.1.
18. Dudal, R. and Eswaran, H. 1988. Distribution, Properties and Classification of Vertisols. In: "*Vertisols: Their Distribution, Properties, Classification and Management*". Wilding, L. P. and Puentes, R. (Eds.), Texas A&M University Printing Center, College Station, Texas. pp. 1-22.
19. Eswaran, H., Beinorth, F. H., Reich, P. F. and Quandt, L. A. 1999. *Vertisols: Their Properties, Classification, Distribution and Management* .Guy D. Smith Memorial Slide Collection. USDA.
20. Gee, G. W., and Bauder, J. W. 1986. Particle Size Analysis. In: "*Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods*", 2nd Edition. Klute, A. (Ed.) Agronomy Monograph No. 9. American Society of Agronomy, Madison, Wisconsin.
21. Heidari, A. 2004. Genesis, Classification and Characterization of Vertisols in Different Climates of Iran. Ph.D. Thesis. Soil Science Department, College of Agriculture, Tehran University.
22. Heidari, A., Mahmoodi, Sh., Stoops, G., and Mees, F. 2005. Micromorphological Characteristics of Vertisols with and Without Smec-

tites in Iran. *Arid Land Res. Manag*., **19(1)**: 29-46.

23. Jeffers, J. D. and Reynolds, R. C. 1987. Expandable Palygorskite from the Cretaceous-tertiary Boundary, Mangyshlak peninsula, U.S.S.R. *Clays Clay Miner*., **35(6)**: 473-476.
24. Khademi, H. and Mermut, A. R. 1999. Submicroscopy and Stable Isotope Geochemistry of Pedogenic Carbonates and Associated Palygorskite in Selected Aridisols from Iran. *Eur. J. Soil Sci.*, **50**: 207-216.
25. Khormali, F. 2003. Mineralogy, Micromorphology and Development of the Soils in Arid and Semiarid Regions of Fars Province, Southern Iran. Ph.D. Thesis, Shiraz University, Iran.
26. Khormali, F., and Abtahi, A. 2003. Origin and Distribution of Clay Minerals in Calcareous Arid and Semi-arid Soils of Fars Province, Southern Iran. *Clay Miner*., **38(4)**: 511-528.
27. Kunze, G. W., and Dixon, J. B. 1986. Pretreatments for Mineralogical Analysis, In: "*Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods*", 2nd Edition. Klute, A. (Ed.) Agronomy Monograph No. 9. American Society of Agronomy, Madison, Wisconsin. pp. 91-100.
28. Little, I. P., Ringrose-Voase, A. J. and Ward, W. T. 1992. Surface Structure in Grey Clay of North Western New South Wales in Relation to Micromorphology, Cation Suite and Particle Size Attributes. *Aust. J. Soil Res*., **30**: 1-16.
29. Mahmoodi, Sh. 1979. Genesis and Characterization of Some Soils from the Karaj-Basin (Iran). Ph.D. Thesis. State University, Ghent, Belgium.
30. McGarry, D. 1996. The Structure and Grain Size Distribution of Vertisols. In: "*Vertisols and Technologies for their Management*". Ahmad, N., and Mermut, A. R. (Eds.), Developments in Soil Science No.24. Elsevier Publ. Netherlands. pp. 231- 260.
31. Mermut, A. R., Dasog, G. S. and Dowuona, G. N. 1996. Soil Morphology. In: "*Vertisols and Technologies for Their Managements*". Ahmad, N. and Mermut, A. R. (Eds.), Developments in Soil Science No.24. Elsevier Publ. Netherlands. pp. 89- 114.
32. Moore, D. M. and Reynolds, R. C. 1989. *X-Ray Diffraction and the Identification and Analysis of Clay Minerals*. Oxford University Press.
33. Neaman, A. and Singer, A. 2000. Rheological Properties of Aqueous Suspensions of Palygorskite. *Soil Sci. Soc. Am. J*. **64**: 427-436.
34. Newman, A. L. 1983. Vertisols in Texas-Some Comments. *Soil Survey Horizons*, **24**: 8-20.
35. Probert, M. E., Fergus, I. F., Bridge, B.J., McGarry, D., Thompson, C. H. and Russell, J. S. 1987. *The Properties and Management of Vertisols*. CAB International, Wallingford.
36. Ross, G. J. 1978. Relationships of Specific Surface Area and Clay Content to Shrink–swell Potential of Soils Having Different Clay Mineralogical Compositions. *Can. J. Soil Sci*., **58**: 159-166.
37. Salinity Laboratory Staff, 1954. *Diagnoses and Improvement of Saline and Alkali Soils. Agriculture Handbook 60*. U.S. Department of Agriculture, Washington, DC.
38. Schafer, W. M., and Singer, M. J. 1976. A New Method of Measuring Shrink-swell Potential Using Soil Pastes. *Soil Sci. Soc. Am. J*., **40**: 805-806.
39. Shirsath, S. K., Bhattacharyya, T. and Pal, D. K. 2000. Minimum Threshold Value of Smectite for Vertic Properties. *Aust. J. Soil Res*. **38**: 189-201.
40. Singer, A. 1989. Palygorskite and Sepiolite Group Minerals. In: "*Minerals in soil environments*". 2nd Ed. Dixon, J. B. and Weed, S. B. (Eds.), Soil Science Society of America, Madison, WI. pp. 829-872.
41. Smith, C. W., Hadas, A., Dan, J. and Koyumdjisky, H. 1985. Shrinkage and Atterberg Limits in Relation to Other Properties of Principal Soil Types in Israel. *Geoderma*, **35**: 47-65.
42. Soil Survey Staff, 1993. *Soil Survey Manual*. U.S. Department of Agriculture, Handbook No. 18. U.S. Government Printing Office, Washington, D.C.
43. Soil Survey Staff, 1999. *Soil Taxonomy; a Basic System of Soil Classification for Making and Interpreting Soil Surveys*. 2nd ed. USDA / NRCS. Washington, DC.
44. Thomas, P. J., Baker, J. C. and Zelazny, L. W. 2000. An Expansive Soil Index for Predicting Shrink–swell Potential. *Soil Sci. Soc. Am. J*. **64**: 268-274.
45. Vadivelu, S. and Challa, O. 1985. Depth of Slickenside Occurrence in Vertisols. J. *Indian Soc. Soil Sci*. **33**: 452-454.
46. Van Wambeke, A. R. 2000. *The Newhall Simulation Model for Estimating Soil Moisture and Temperature Regimes*. Deptartment

of Crop and Soil Sciences. Cornell University, Ithaca, NY. USA.

47. Whittig, L. D., and Allardice, W. R. 1986. X-Ray Diffraction Techniques, In: "*Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods*". Klute, A. (Ed.), 2nd Edition. Agronomy Monograph No. 9. American Society of Agronomy, Madison, Wisconsin.
48. Wilding, L. P. and Tessier, D., 1988. Genesis of Vertisols: Shrink-swell Phenomena. In: "*Vertisols: Their Distribution, Properties, Classification and Management*". Wilding L. P. and Puentes, R. (Eds.), Texas A&M University Printing Center, College Station, Texas.
49. Yaalon, D. H., and Kalmar, D. 1978. Dynamics of Cracking and Swelling in Clay Soils: Displacement of Skeleton Grains Optimum Depth of Slickensides and Rate of Intrapedonic Turbation. *Earth Surf. Process. Land,* **3**: 31-42.
50. Yerima, B. P. K., Calhoun, F. G., Senkayi, A. L., and Dixon, J. B. 1985. Occurrence of Interstratified Kaolinite-smectite in El-Salvador Vertisols. *Soil Sci. Soc. Am. J.*, **49**: 462-466.
51. Yousif, A. A., Mohamed, H. H. A. and Ericson, T. 1988. Clay and Iron Minerals in Soils of the Clay Plains of Central Sudan. *J. Soil. Sci.*, **39**: 539-548.

تنوع کانیهای رس در خاکهای ورتی سول سه ناحیه اقلیمی مختلف در غرب ایران

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چکیده

برخلاف باورهای رایج در باره خاکهای انبساط‌پذیر، اطلاعات قابل توجهی در دست است که نشان می دهد کانیهای رسی موجود در ورتی سولها محدود به سیلیکاتهای لایه‌ای انبساط‌پذیر نمی‌باشند. بلکه وجود مقادیر زیاد رس، خصوصاً رس ریز، بدون توجه به نوع آن، بالاخص در شرایطی که خشک و مرطوب شدن متناوب خاک بوفور صورت بگیرد، می‌تواند قابلیت انقباض و انبساط کافی در این خاکها را افزایش پیدا کند. در این مطالعه برخی ورتی سولهای تشکیل‌یافته روی مواد مادری و اقلیمهای متفاوت ایران بررسی شدند. ورتی سولهای استان فارس (جنوب غرب ایران) روی رسوبات آهکی با رژیم رطوبتی خاک از نوع یوستیک و رژیم حرارتی هایپرترمیک و ترکیب کانی‌شناسی غالب پالی گورسکایت- کلرایت تشکیل یافته‌اند. ورتی سولهای استان لرستان (غرب میانی ایران) نیز روی رسوبات آهکی و رژیم رطوبتی خاک از نوع زریک و رژیم حرارتی ترمیک با ترکیب کانی‌شناسی غالب از نوع ورمیکولایت تشکیل شده‌اند. در استان کرمانشاه، ورتی سولها روی مواد مادری سنگ آهک یا رسوبات آهکی تشکیل یافته‌اند و دارای رژیم رطوبتی و حرارتی خاک زریک-ترمیک هستند. در استان اردبیل ورتی سولها بر روی رسوبات حاصل از سنگهای آذرین تشکیل یافته‌اند و دارای رژیم رطوبتی و حرارتی از نوع زریک- مزیک تشکیل شده‌اند. به غیر از ورتی سولهای استان فارس بقیه ورتی سولهای مطالعه شده ورتی سولهای عادی می‌باشند که شامل کانی رسی مونتموریلونایت به مقدار کافی می‌باشند. این مطالعه نشان می‌دهد که اندازه حفرات موجود در بین ذرات که بستگی به اندازه ذرات اولیه تشکیل‌دهنده آنها دارد، بدون توجه به نوع آنها، می‌توانند قابلیت انقباض و انبساط شدید در خاکهای مطالعه شده در ایران را توضیح دهند.

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