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A Mineralogical and Morphological Characterization of Shrink-swell Soils of the Northern Plains of Jordan

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Abstract: X-ray diffraction patterns have been employed to study the mineralogy of five pedons representing the major shrink-swell soils developed on basalt and limestone in the northern plains of Jordan. The soils are calcareous, dark brown to brown with low organic matter contents (<1%), had clayey textures and calcium carbonate accumulation. Kaolinite was found in minor quantities in all sites. Smectite, kaolinite, illite and palygorskite were abundant in the clay fraction. Smectite was found to be the most abundant of the clay mineral in the studied pedons. Quartz, plagioclase, kaolinite, palygorskite vermiculite/illite and smectite/vermiculite were identified in the silt fraction of the surface horizons. Slickensides, cracks and gilgai are observed at macroscopic levels. Clay illuviation was not active in the studied soils because of pedoturbation.

Key words: Shrink-swell · smectite · mineralogy · semi-arid environment · soil genesis

INTRODUCTION

Shrink-swell soils represent an important soil resource in the northern plains of Jordan. This type of soils occupy more than half of the cultivable land in northern Jordan. They are particularly associated with sedimentary and igneous parent rocks, subdued relief and an annual precipitation of 300-450 mm. The mineralogical composition of these soils is the foundation of their potential productivity.

There are relatively few well-documented mineralogical composition studies that has been reported regarding the shrink-swell soils in the northern plains of Jordan.

The most unique feature of these soils is their ability to shrink and crack as drying progresses and swell and become very plastic and cohesive on wetting. Shrink-swell process is enhanced by wetting and drying patterns after gilgai formation [1]. Shrinking and swelling of soils with changes in moisture conditions impact their use for agricultural, engineering and environmental purposes. Clay mineralogy is one of the factors affecting the extent and nature of shrinking and swelling of these soils as well as their cation exchange capacity.

Smectite dominates the soil-clay mineralogy in these soils. Genesis of smectite requires the accumulation of basic cations such as Ca and Mg. Ca and Mg ions are either inherited from the sedimentary rocks (marls or fine-grained calcareous alluvium) or by weathering in case of crystalline or eruptive basic rocks (such as basalt or dolerite). Shrink-swell soils were found to contain smectite as dominant or co-dominant in clay fraction [2].

Kaolinite minerals are always present in shrink-swell soils, whatever the origin, location or environmental conditions. The increase in kaolinite can be related to greater weathering regime [3]. Illite is also reported as abundant in shrink-swell soils. Micas in these soils may occur in the sand, silt and the clay fractions. Feldspars also are very common in these soils. Upon weathering alkali feldspars and plagioclase feldspars supply potassium and calcium cations as plant nutrients. Carbonates are also common mineralogical constituents of shrink-swell soils. Their occurrence depends heavily on the origin of parent material and past and current environmental conditions [4]. Also, several types of interstratified clay minerals have been reported. Shadfan [5] reported the presence of mica-smectite in shrink-swell soils in Jordan. Dominance of smectite minerals in the clay fraction results in appreciable shrink-swell potential which results in the formation of cracks and slickensides. Bhattacharyya *et al.* [6] indicated that shrink swell process of soils is related to smectite content and cannot

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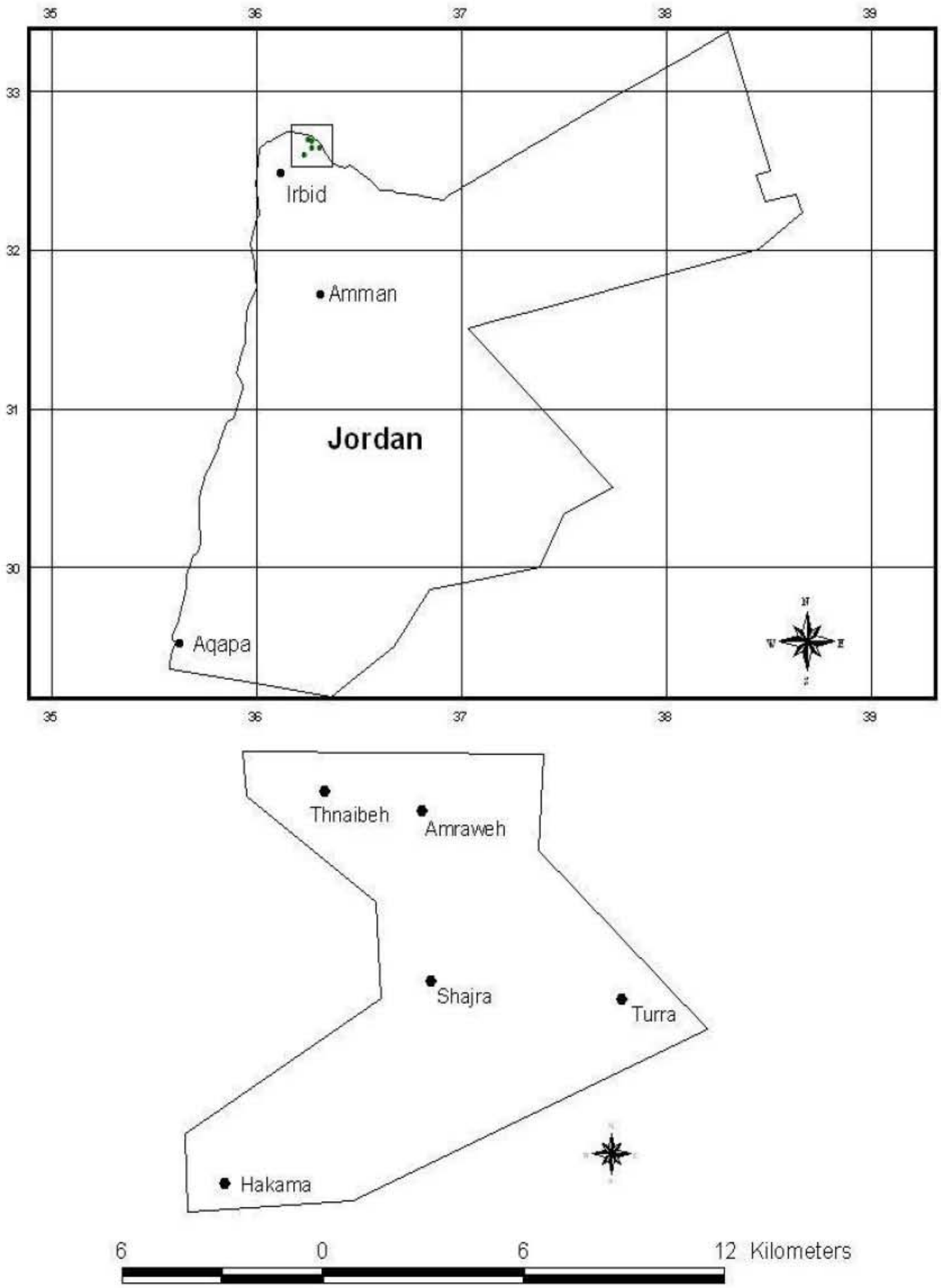

Fig. 1: Map showing location of the studied sites

be caused by kaolinite. Karathanasis and Hajek [7] indicated that shrink-swell phenomena are positively correlated with the content of expansible mineral.

This study will provide basic soil mineralogical data needed by researchers and landuse planners for understanding the genesis of these soils, quaternary paleoclimates and their resulting pedogenic effects.

The objective of this paper is to present data for mineralogical analysis of the shrink-swell soils from northern plains of Jordan. To provide a means of understanding the soil properties, genesis and land use capabilities.

MATERIALS AND METHODS

Location: Five representative sites developed on different parent material types and receive different amounts of annual rainfall were selected to represent the major shrink-swell soil areas in northern plains of Jordan. The study area is approximately 90 Km north of Amman (Fig. 1). The parent materials are derived from alluvium and colluvium basalt and limestone. Table 1 shows the geology and parent material of each study site.

Climate: The climate of the studied area is of Mediterranean type with an average annual precipitation ranging between 300 and 450 mm [8]. The rainy season extends from November to March. This climatic region is in the 600 m elevation zone above sea level. The mean winter temperature range from 5 to 9°C and the mean summer temperature range from 22 to 29°C.

Laboratory procedures: Oriented clays from selected horizons of the soils were analyzed by XRD to determine the clay minerals. Treatments of samples included Mg saturation and glycerol solvation and K saturation and heating to 550°C as outlined in Jackson [9]. Data were obtained using a Philips X-ray diffractometer and graphite-monochromated *Cu-Ka* radiation generated at 40 mA and 45 kV. Analyses was carried out at the mineralogy laboratory at Yarmouk University.

Table 1: Slope, Parent material and landuse of the studied sites

Site	Precipitation (mm)	Slope gradient	Parent material	Present landuse
Hakama	400	Nearly level (1%)	Basalt	Cereal crops
Ramtha	300	Very gently sloping (1-2%)	Limestone	Irrigated forage
Shajara	350	Very gently sloping (1-2%)	Limestone	Summer crops
Thnaibeh	450	Nearly level (1%)	Basalt	Cereal crops

The soil samples taken from each horizon from all studied sites were air dried, crushed and sieved to remove the >2 mm fraction. 40 grams of unground samples were used for particle size determination and fractionation [10] Soil pH was measured on 1:1 soil: water suspensions [11]; soluble salts were determined by measuring the electrical conductivity of 1:1 soil: water extracts [12]; organic matter was determined using the Walkley-Black method [13]; and calcium carbonate equivalent values were obtained using the acid neutralization method [14].

RESULTS AND DISCUSSION

Mineralogical composition: Clay minerals were identified based on their relative intensity in the X-ray diagrams. XRD examination of the clay fractions of studied soils indicates a dominant peak of kaolinite at 0.7 nm and a dominant peak of smectite at 1.4 nm. In the Mg-saturated, air-dried state, the smectite phase exhibited a basal spacing of 1.5 nm, which shifted to 1.7 nm after ethylene glycol solvation in all samples. The studied soils contained smectite, which is fairly well crystallized as it yields a sharp basal reflection upon glycollation. The dominance of smectite among clay minerals is attributed to the calcareous nature of these soils which enhance smectite formation and preservation.

The presence of Kaolinite plays a major role in shrink-swell potential of these soils but despite the presence of kaolinite in all horizons, the dominance of smectitie control the shrink-swell processes of these soils.

Carbonates are common minerals in the studied soils. They occur as $CaCO_3$. The sand fractions of all A horizons were dominated by quartz.

The x-ray diffraction analysis indicate the presence of the following minerals arranged in descending order of abundance: Smectite, kaolinite, illite and palygorskite. Smectite and kaolinite were uniformity distributed with depth while illite content decreased with depth (Table 3).

Quartz, plagioclase, kaolinite, palygorskite vermiculite/illite and smectite/vermiculite were identified in the silt fraction of the surface horizons. The presence of palygorskite at the surface indicate the weakness of the chemical weathering and is attributed to the eolian activities.

The minerals distribution was not highly related to the present rainfall distribution, but rather to the type of the parent material and paleoenvironmental conditions. The presence of some minerals, such as palygorskite illite and plagioclase, especially, at the surface, suggests that these minerals were transported by wind that characterize arid climate.

Table 2: Soil properties and classification of the studied sites

Horizon	Depth, cm	Moist color	CEC cmol/kg	pH	EC, ds/m	O.C %	$CaCO_3$ %
		Hakama: Chromic haploxererts					
Ap	0-15	5YR 3/4	44.1	7.64	0.45	0.82	11.3
Bss	15-65	5YR 3/4	43.2	7.71	0.27	0.33	12.8
Bssk	165-125	5YR 3/3	43.9	7.73	0.33	0.22	13.1
Bssk2	125-175	7.5YR4/4	42.8	7.78	0.35	0.18	24.6
		Ramtha: Chromic haploxererts					
Ap	0-20	5YR 3/4	41.2	7.64	0.45	0.82	11.3
Bk	20-80	5YR 3/4	39.6	8.24	0.34	0.33	17.2
Bssk1	80-120	5YR 4/4	42.9	8.30	0.45	0.30	18.5
Bssk2	120-165	5YR 4/6	37.1	8.32	0.62	0.26	19.9
		Shajra: Chromic haploxererts					
Ap	0-20	7.5YR 3/4	53.2	7.88	0.28	0.60	23.8
Bssk1	20-50	5YR 4/4	51.3	7.94	0.24	0.46	23.9
Bssk2	50-85	5YR 3/4	52.0	7.99	0.26	0.41	23.9
Bssk3	85-140	5YR 3/4	51.8	8.02	0.28	0.31	23.9
		Amraweh: Chromic haploxererts					
Ap	0-25	5YR 3/3	48.2	7.82	0.53	0.50	18.6
Bw	25-70	5YR 3/3	46.1	8.12	0.26	0.42	19.6
Bssk1	70-100	5YR 3/4	47.8	8.25	0.35	0.39	19.6
Bssk2	100-160	5YR 3/4	46.5	8.20	0.55	0.26	20.3
		Thnaibeh: Typic haploxererts					
Ap	0-10	5YR 3/2	56.8	7.88	0.30	0.50	23.9
Bw	10-35	5YR 3/2	54.2	8.03	0.34	0.48	23.9
Bss1	35-100	5YR 3/3	56.3	8.27	0.45	0.38	24.0
Bss2	100-140	5YR 3/4	51.9	8.36	0.62	0.29	24.0

Table 3: Particle size distribution and clay minerals for the studied sites

Horizon	Depth/cm	Sand	Silt	Clay	Mineral makeup
			%		
			Hakama		
Ap	0-15	4.1	47.4	48.5	Sm = 4, Ka = 2, MI = 3,
Bss1	15-65	4.2	48.3	47.5	Sm = 4, Ka = 2, MI = 2
Bssk1	65-125	4.8	49.2	46.0	Sm = 4, Ka = 2, MI = 1
Bssk2	125-175	4.7	46.8	48.5	Sm = 4, Ka = 2, MI = 1
			Ramtha		
Ap	0-20	5.8	41.7	52.5	Sm = 3, Ka = 2, MI = 2
Bk	20-80	6.0	38.4	55.6	Sm = 3, Ka = 2, MI = 1
Bssk1	80-120	6.1	40.1	53.8	Sm = 3, Ka = 2, MI = 1
Bssk2	120-160	6.0	40.2	53.8	Sm = 3, Ka = 2, MI = 1
			Shajara		
Ap	0-20	8.2	33.8	58.0	Sm = 3, Ka = 3, MI = 2
Bssk1	20-50	8.5	32.2	59.3	Sm = 4, Ka = 3, MI = 1
Bssk2	50-85	7.9	31.6	60.5	Sm = 4, Ka = 3, MI = 1
Bssk3	85-140	8.3	33.1	58.6	Sm = 4, Ka = 3, MI = 1
			Amraweh		
Ap	0-25	7.2	39.5	54.0	Sm = 3, Ka = 2, MI = 2
Bw	25-70	7.1	38.4	54.5	Sm = 3, Ka = 2, MI = 1
Bssk1	70-100	6.9	38.0	55.1	Sm = 3, Ka = 2, MI = 1
Bssk2	100-160	7.0	34.7	58.3	Sm = 3, Ka = 2, MI = 1
			Thnaibeh		
Ap	0-10	5.2	32.3	62.5	Sm = 3, Ka = 2, MI = 2
Bw	10-35	5.0	30.5	63.5	Sm = 3, Ka = 2, MI = 2
Bss1	35-100	5.1	31.9	63.0	Sm = 3, Ka = 2, MI = 1
Bss2	100-140	5.1	31.9	63.0	Sm = 3, Ka = 2, MI = 1

•Sm = smectite, Ka = kaolinite, MI = mica, 1 = trace, 2 = small, 3 = moderate, 4 = abundant, 5 = dominant, 6 = intermediate

The lack of variation in clay minerals suggests that, even during wetter period of the Pleistocene, leaching did not occur to the extent of removing enough silica to favor kaolinite stability and that the intensity of soil processes influencing clay formation has been similar.

Pedogenic processes: In spite of the low Organic Matter (OM) content The colour of the studied soils ranged from dark brown to reddish brown. Differences in colour are in connection with different physiographic positions where the dark brown soils occupied low-lying areas and the reddish soils occupied the gentle sloping uplands.

Shrink and swell processes resulted in the formation of slickensides and the development of deep and wide cracks. Slickensides, wedge-shaped aggregates, cracks and gilgai are observed at macroscopic levels. Clay illuviation was not active in the studied soils because of pedoturbation.

Soil physical and chemical characteristics:

pH and electrical conductivity: The studied soils are alkaline because they are mostly derived from calcareous or base-rich parent materials. pH values ranged from 7.64 to 8.36 (Table 2).

The electrical conductivity values of the saturation extracts ECe ranged from 0.24-0.62 dSm^{-1}, indicating that the soils are not saline (Table 2).

Cation exchange capacity and exchangeable cations: Generally, shrink-swell soils have a relatively high Cation Exchange Capacity (CEC) which ranged from 37.1 to 56.8 cmol kg^{-1}(soil). The amount and type of clay, in particular the smectitec content and the organic matter content are the determinant factors.

Soil texture: The studied soils displayed similar soil physical and chemical characteristics. The clay content ranged between 46.0 and 63.5% and was almost identical within the same soil profile, both in its degree of variation as well as in its average value.

CONCLUSIONS

Analysis of the clay fractions by x-ray diffraction indicated that Smectite, kaolinite, illite,palygorskite and quartz are common to all studied sites. All clay fractions contain smectite as either the dominant or the co-dominant phase, while kaolinite was a common accessory phase.

There was no consistent difference in any of the physical or chemical characteristics between soils within the same profile, except for the organic matter which was considerably higher in the A horizons as expected.

A decrease in quartz and feldspar contents and an increase in layer silicate clay minerals occur with decrease in particle size.

Shrink-swell soils can be recognized as mainly fine in texture, dark in color, commonly lacking distinct horizonation and possessing characteristically extreme shrink-swell attributes with changes in soil moisture content.

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