

## Clay Mineralogy of the Soils above Basalt from Azraq Area, Jordan

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### ABSTRACT

Twelve clay samples were taken from three pits below the basaltic loose veneer rubble down to the basaltic bedrock in order to discuss the origin of the clay minerals in relation to the origin of the soil. The non-clay minerals present are: quartz, calcite and feldspar which are abundant in all soil samples. The basaltic bedrock as well as the loose fragments are made up of fresh basalt. There is a sharp contact between both the basalt fragments and the soil. The clay minerals are: palygorskite, kaolinite and a mixed-layer of illite/smectite. These were observed in the distribution of the clay minerals, and no transitional phases were observed along the pits. The clay minerals were formed by the effect of wind-blowing /detrital and transported. Consequently, soil accumulation north of Azraq Al-Druze seems to be wind blown and not due to basalt alterations.

**KEYWORDS:** Clay minerals, Basaltic soil, Wind blowing, Azraq Area, Jordan.

### INTRODUCTION

Azraq basin is situated 110 km northeast of Amman (Fig. 1). The basin comprises several varying environments such as: mud flats, alluvial fans and wadies. Most of the northern part of the area is covered by alluvium silt to mud/clay soil. The fine silts and clays are deposited to form mud flats or silt flats along Al-Abed Unit north of Azraq Al-Druze area (Ibrahim, 1996 and 1993).

The Azraq basin seems to have evolved as a negative depression since late Turonian (Yasin, 1992). Wadi As-Sir Formation (Turonian) as well as the whole Belqa Group were penetrated in the wells for petroleum exploration. About 130 m of Recent Subrecent sediments are present in Al-Azraq depression (Faraj, 1988; Qaadani, 1992). They consist

of alluvial fans and gypsum at the periphery of the depression. Within their center, the sediments consist of diatomite, clay and carbonates (Alali et al., 2006; Khouri and Qaadani, 2003; Khouri, 1980; Malabeh et al., 2002; Abed and Kharabshe, 2000; Qararah and Alali, 1995).

The Azraq basin lies within the arid region of the eastern desert and is characterized by a typical desert climate. The mean annual rain fall is about 50 mm.

The study area is a mud flat (Qa Al-Azraq), which has developed in the low topographic areas when the ground was level and flat. It was formed as a result of regional and local faults which produced a small depression, where mud accumulated from standing water fed by ephemeral wadies discharging into mud flats (Ibrahim, 1996). The annual flash flooding causes water to accumulate and remain for a while allowing fine silt and sand to form mud flats or silt flats. Clay of various amounts evaporates and silty clay is formed

with rock fragments (basalt fragments).

The aim of this work is study the origin of the clay minerals in the mud flat area and the relation between

the clay minerals and basaltic rocks surrounding the study area.

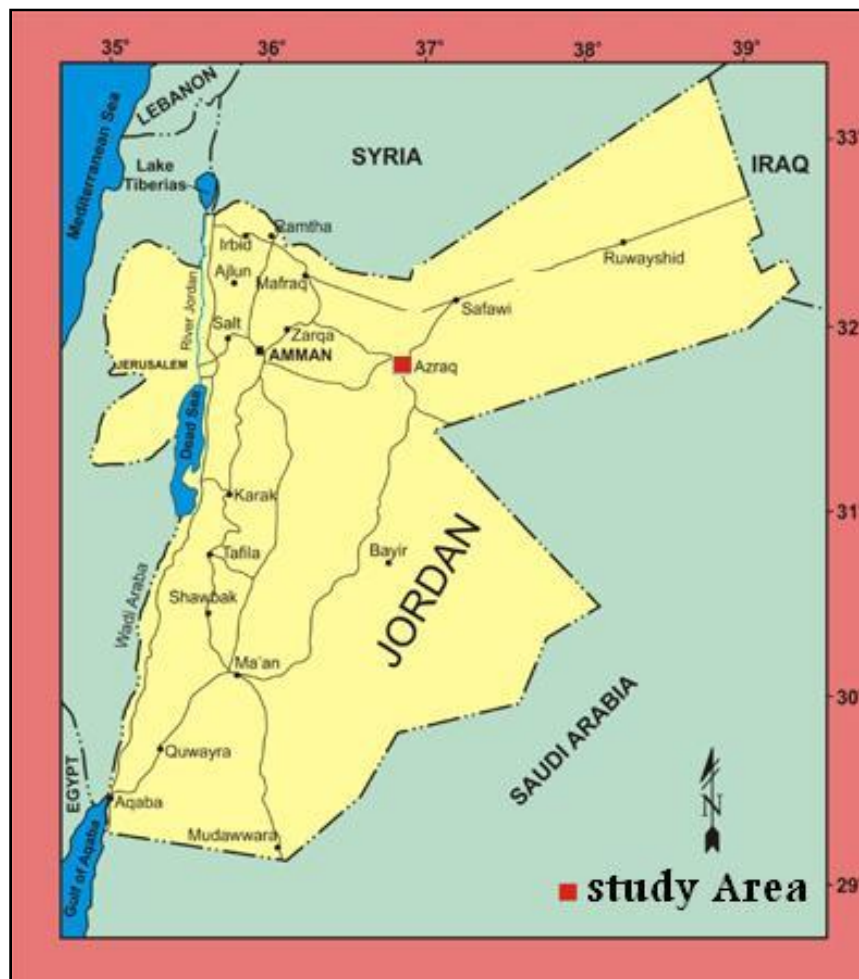


Figure 1: Location of studied area (after NRA, Jordan)

### LITHOLOGY OF THE SOIL PROFILE

Three pits were dug, Wadi Hassan, Wadi Unquiyya and Tal Aseikhem (Fig. 2). The lithology of the pits at the three sites is similar; about one meter of brownish-yellowish soil profile consisting of silt-size materials, overlying the basaltic bedrock which is devoid of layering and variation of colour (Figure (3)). The surface of soils in the study area is covered by fresh

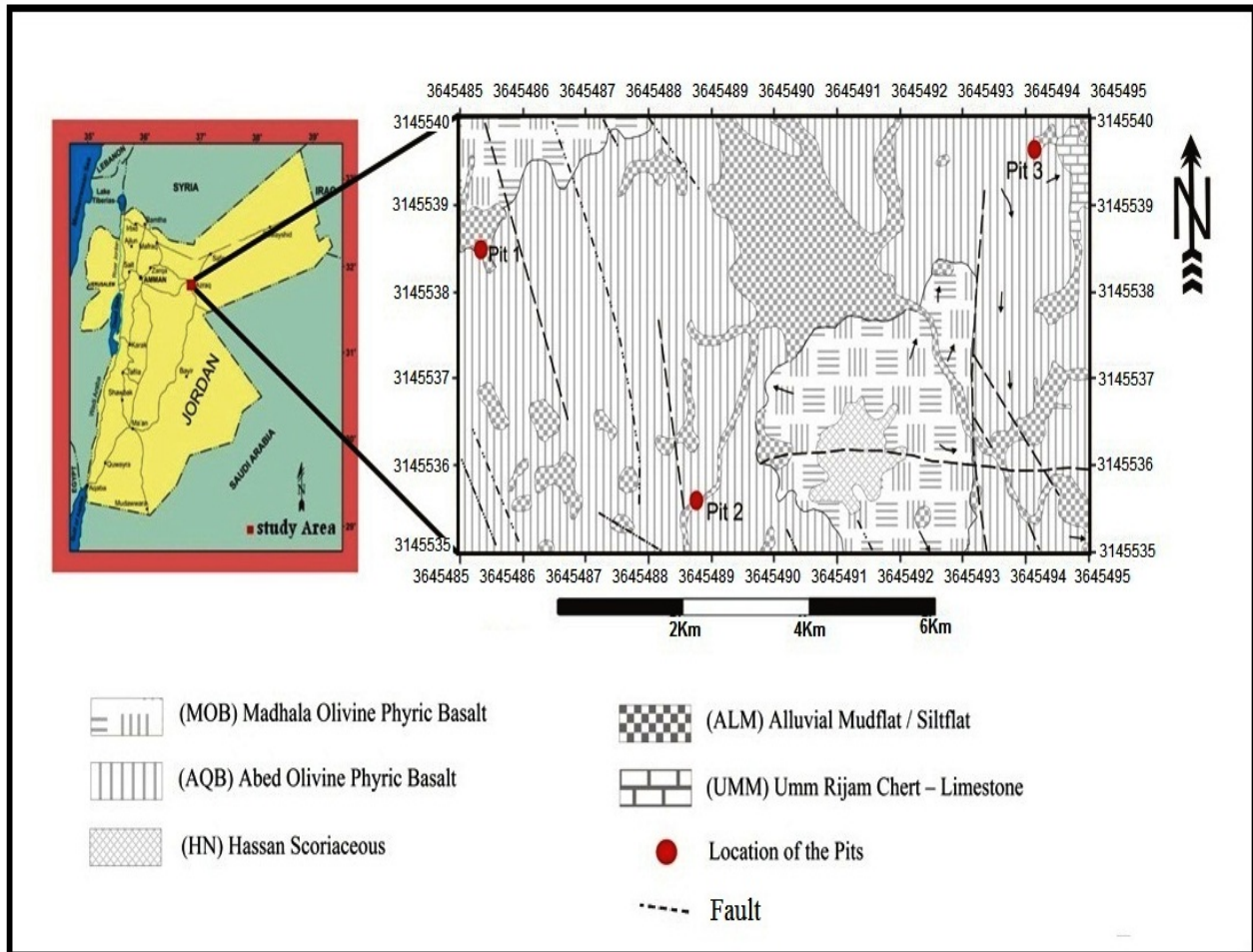
basaltic fragments, ranging in size from granules to pebbles.

### SAMPLING AND ANALYTICAL TECHNIQUES

Twelve samples were collected from the three pits (Fig. 2), representing the various soil horizons about one meter deep. Ten grams of each sample were hand-ground in a mortar. The powdered materials were

treated in order to separate the clay fraction using Atterberg Techniques (Jackson, 1975). Three slides of less than two micron size fraction were X-rayed, in addition to random whole soil samples. Thin sections of each sample were prepared for petrographic

investigation. Scanning electron microscopy was used for studying undisturbed gold coated samples to investigate the nature of morphology of clay crystals, at the University of Jordan.



**Figure 2: Location map showing the geology and three pits' study (1)- Wadi Unquiyya, (2)- Wadi Hassan and (3)-Tal Aseikhem (Ibrahim, 1993)**

## RESULTS

### PETROGRAPHY

Petrological work showed that the basalt samples are fresh in nature; no weathering was seen except for the alteration olivine to iddingsite in some samples, which indicates a slight alteration. The minerals

present are: plagioclase as laths, olivine and pyroxene as phenocryst, all imbedded in a fine grained matrix.

Clay minerals are present as an argillaceous matrix associated with fresh fragments of basaltic rocks, with a sharp contact between them. The soil samples are composed of fragments of basalt and angular to subangular quartz. The fine part of the soil consists of

silt size carbonates (calcite) stained in red or yellow iron oxides. Calcite is also present as cement or in small cavities. Fine grains of gypsum associated by silt

are present in some samples from the lower part of one pit (Wadi Hassan pit).

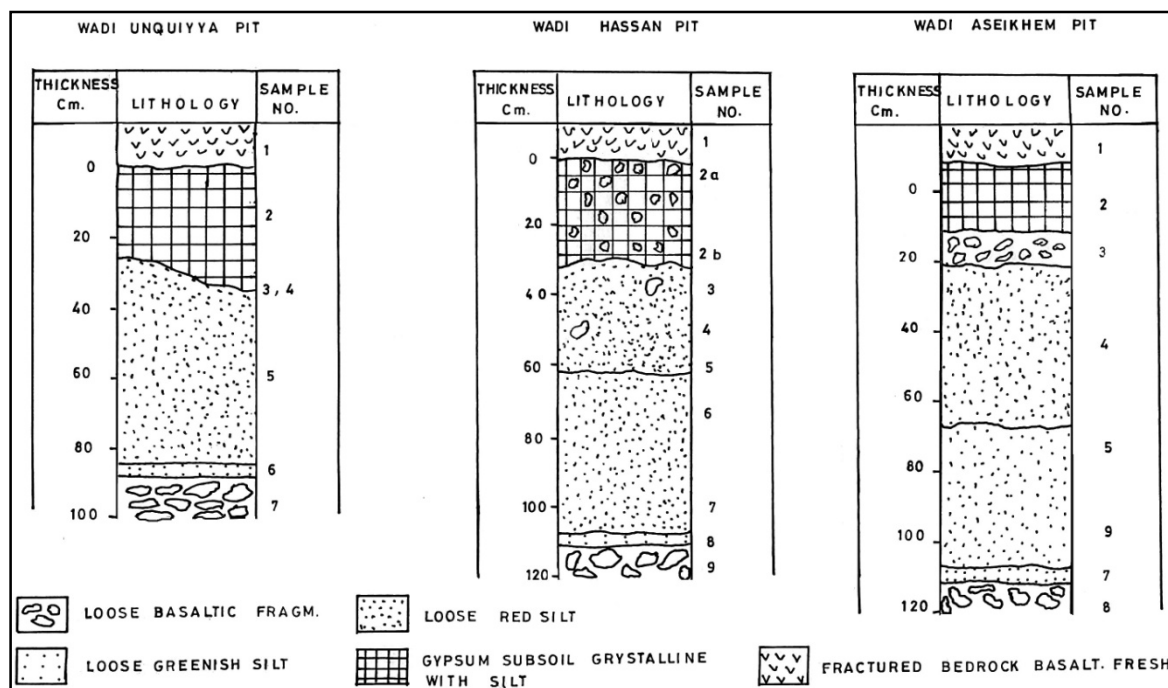


Figure 3: The lithology of the three soil profiles

## CLAY MINERALOGY

### X-RAY DIFFRACTION ANALYSIS

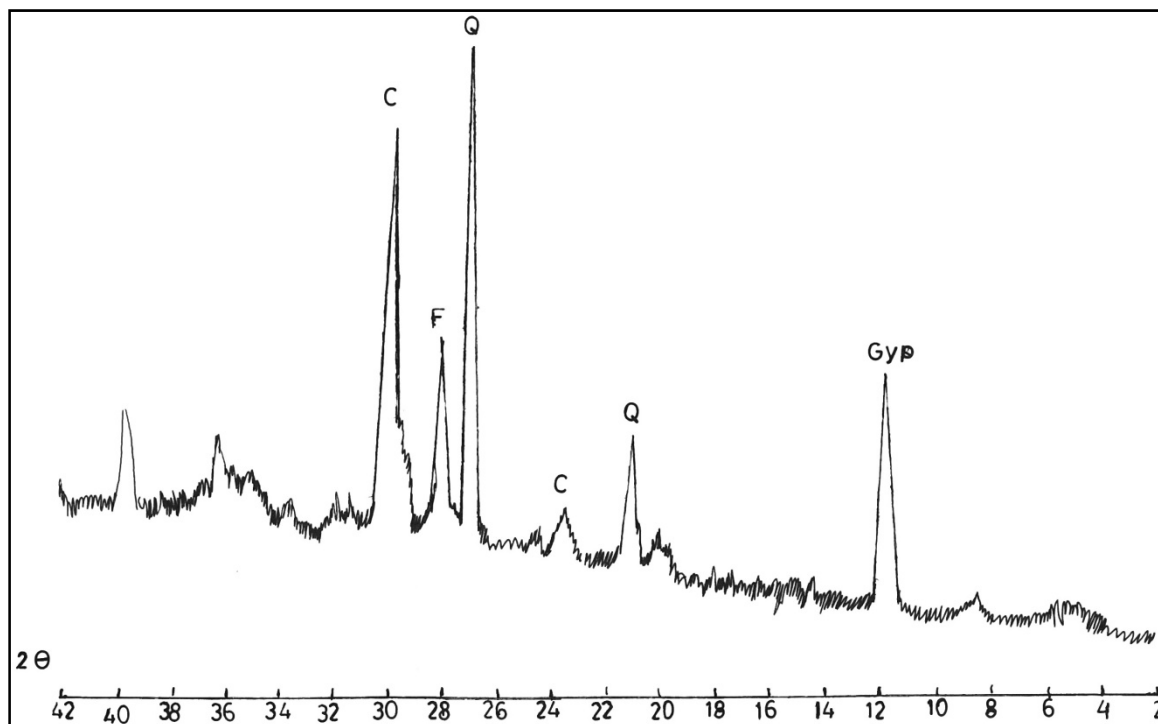
For random preparations, the mineralogical composition of the major non-clay minerals detected is as follows: quartz, calcite, feldspar and gypsum (Fig. 4). The stronger characteristic peaks of each mineral were used in the quantitative analysis as shown in Table 1. The oriented prepared samples for XRD patterns produced by air-dried, heated and glycolated samples indicated that palygorskite, kaolinite and a mixed-layer of illite /smectite are present in all samples.

**Kaolinite (K):** Kaolinite is present in all samples, the most characteristic peak of kaolinite appears at 0.72  $\mu\text{m}$  (Moore and Renodls, 1989), which is not affected by glycolation, but disappears upon heating to 550°C

for two hours (Fig. 5). The crystallinity of kaolinite varies from well to poorly crystalline. The (001) and (002) peaks of the well crystalline type are sharp and symmetrical. The asymmetrical (001) and (002) reflection and the absence of other peaks indicate a poorly crystalline type (Brindly and Robinson, 1946).

**Palygorskite (P):** This mineral is the dominant clay mineral in the studied samples. It is identified by the (110) reflection which appears at 1.05  $\mu\text{m}$  (Fig. 6). The first order peak is not affected by glycolation, but by heating for two hours at 800°C, the reflection disappears.

**Mixed Layer of Illite/Smectite (I/S):** These minerals are present in all samples as minor clay minerals (Fig. 7). The expandability of the mixed-layer is about 40-50% and is randomly stratified using the simulation diagrams (Reynolds and However, 1969).



**Figure 4: X-ray diffraction for a randomly oriented sample**  
 Gyp = gypsum    Q = quartz    C = calcite    F = feldspar

### SCANNING ELECTRON MICROSCOPY

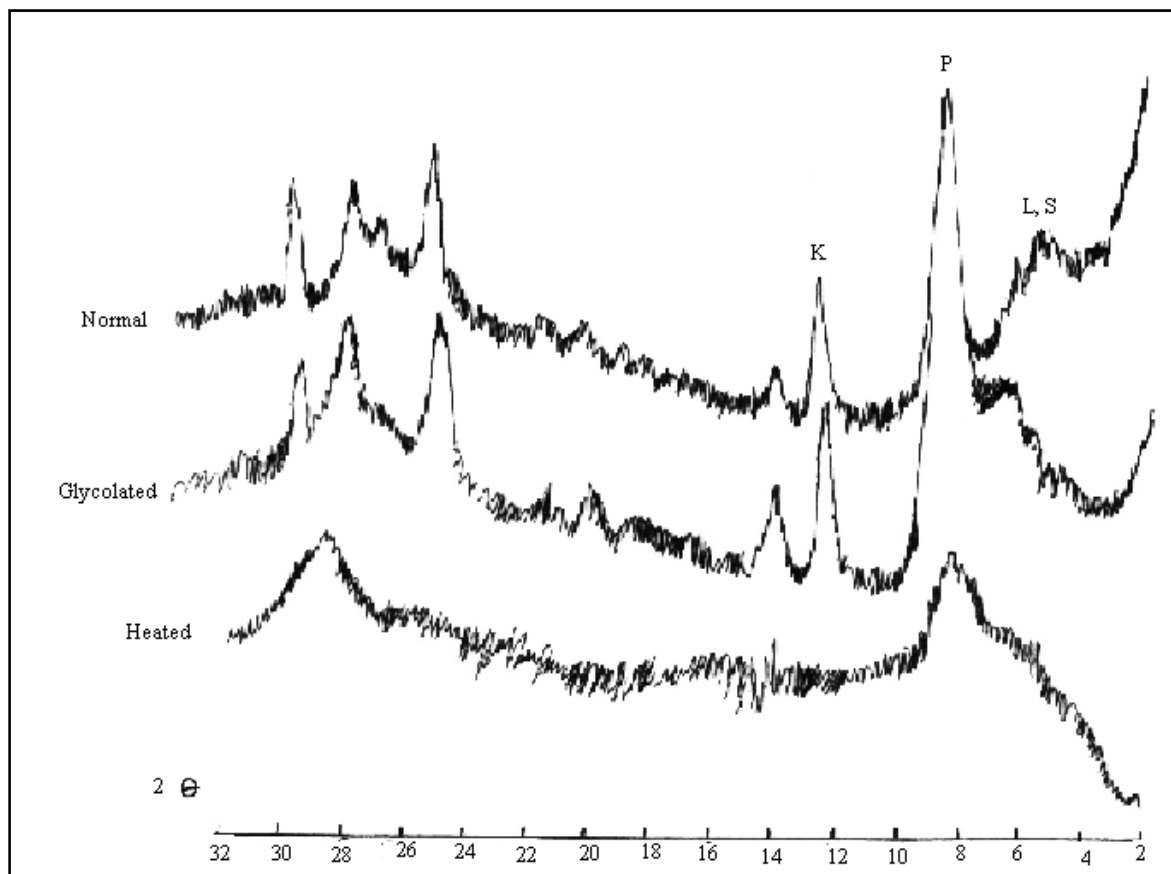
Intact samples were chosen for scanning electron microscopic studies to characterize the shape (morphology) of the clay minerals. Friable soil samples were prepared more than twice to get acceptable graphs. The electron micrographs show that the clay minerals present do not indicate a clear shape as shown in Figures (8, 9 and 10). Thus it is identified by the SEM. Kaolinite particles are present and seen as broken and unihedral crystals (Fig. 8).

Palygorskite also was detected in one sample as small fibers sprouting out from the mixed layer of illite/smectite (Fig. 9). In the other samples, no fibers or laths of palygorskite have been detected in the samples by the X-ray studies. Mixed-layer of illite/smectite is also present as separated flakes and plates (Fig. 10).

### DISCUSSION

The study area is occupied by about 100 km<sup>2</sup> of basalt rocks of Al-Abed Alkali Olivine Unit (Ibrahim, 1996; Moffat, 1988). The area studied is a small basin of alluvial silt and silt flats developed in low topographic areas, when the ground was level and flat. The surface area is covered by basalt rock fragments and soil. The thickness of the soil profile is about one meter and it is composed of yellowish brown to reddish clay and various amounts of evaporates (gypsum). The soil is composed mainly of clay to silt size fractions.

Now, we discuss the origin of the clay minerals; whether they were produced by chemical weathering of basaltic rocks or autogenetic to detrital sediments.



**Figure 5: X-ray diffractograms of the separated clay size fraction for untreated, glycolated and heated to 550°C, ordered sample from Wadi Hassan**  
**I.S. = mixed layer illite/smectite    K = kaolinite    P = palygorskite**

#### Mineralogical and Petrographical Investigation

- 1- There are abundant sand to silt sized quartz and calcite crystals in all samples studied. It is well-known that basalt does not have quartz as a rock forming mineral. Consequently, quartz and calcite must have been brought to this area, most probably by wind or water annual flooding (Ibrahim, 1996). This basalt has never been covered by water except in the course of small wadies draining it. It is rather difficult to form calcite by chemical weathering of basalt. Thus, there is no possibility to incorporate the quartz grains in the studied soil except by wind-blown material from the nearby Azraq basin sediments.
- 2- The presence of small fresh basaltic rock fragments with sharp boundaries in the soil matrix was detected. This is again another indicator that basalt did not suffer alteration to produce the soil. We suggest that these basaltic fragments must have been brought to the area by the annual flash flooding of the wadi sediments.
- 3- Silt size calcite is rather abundant in the soil. It is rather difficult to form this calcite by the chemical weathering of basalt. It is much easier separated as wind-blown fine grain carbonate brought from the carbonate rich nearby area of Umm Rijam chert limestone formation.

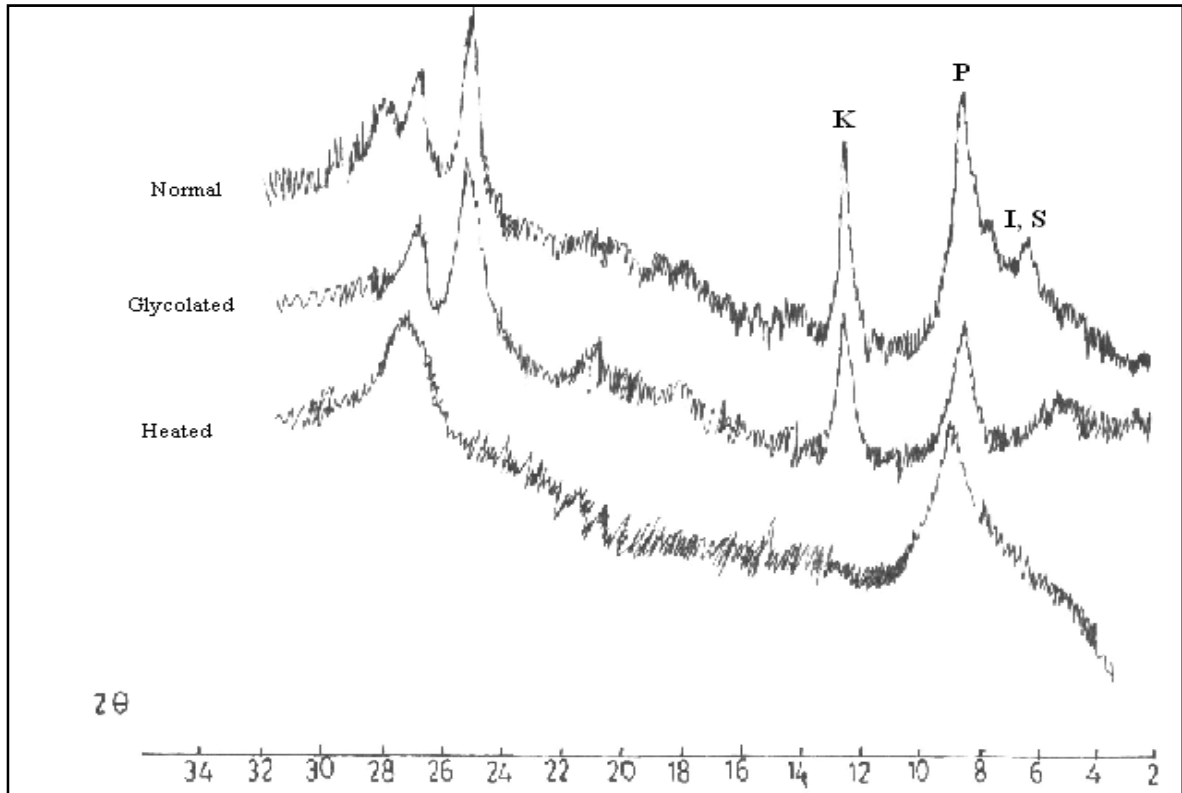


Figure 6: X-ray diffractograms of the separated clay size fraction for untreated, glycolated and heated to 800°C, ordered sample from Wadi Aseikhem

- 4- The soil profile is rather homogenous throughout its one meter thickness and classified within the intra zonal horizons. Thus, chemical alteration of basalt bed rock is here rejected because it cannot explain the homogeneity of the soil profile.
- 5- The basaltic bedrock as well as the loose top veneer are all made up of insitic basalt. No altered basalt is seen in the three pits or at the surface.

#### Clay Minerals Investigation

- 1- The presence of kaolinite in this area is attributed mainly to transportation by deflation from the surrounding areas; this is clear from the SEM Figures which show anhedral and broken crystals of kaolinite. In general, kaolinite forms mainly from feldspar and mica alteration, in conditions of low  $aK^+/aH^+$  ratio (Curtis, 1983; Brown, 1961). This process takes place in soils and sediments

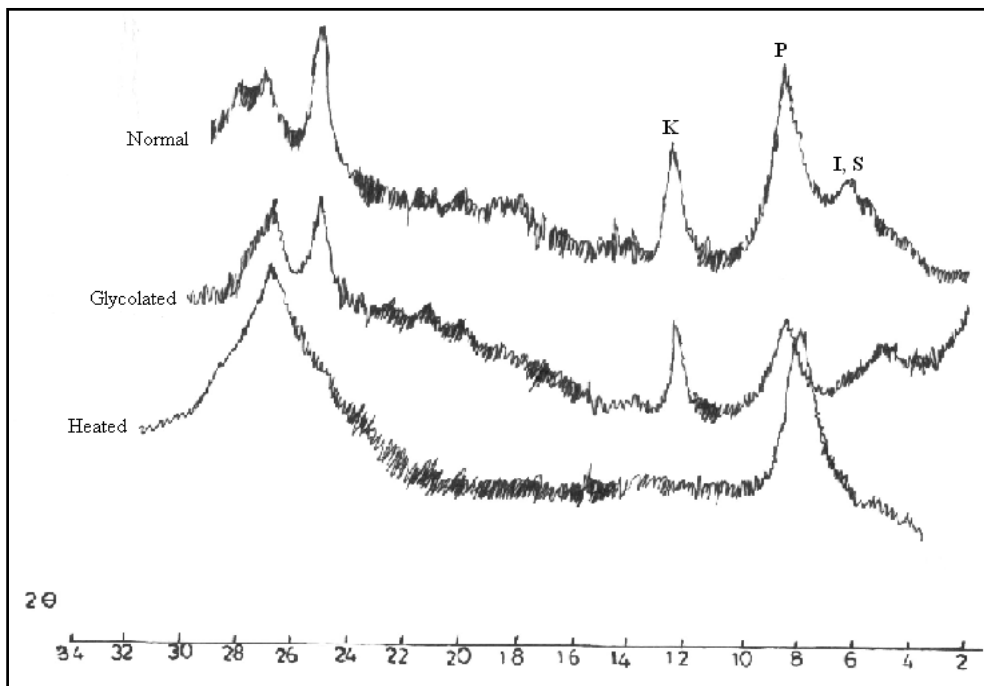
subjected to important drainage by meteoric water flows (Bjorlykke, 1998). Such condition does not occur in the studied area which is considered as an arid region.

- 2- There are numerous studies on the genetic palygorskite in continental (e.g., Singer, 1984; Velde, 1985; Jones and Galan, 1988) and chemical environments, palygorskite precipitates in the basin reach of basalt, or smectite is transformed to palygorskite in the calcareous soils (Millot, 1970; Callen, 1984). It seems that palygorskite is a possible precursor mineral for smectite formation in arid and semi-arid environments (Mostafa et al., 2008). As is known, clay minerals are found especially in soil, calcrete and lacustrine deposits, and there is general agreement that its formation requires alkaline conditions, high Mg and Si activity and arid or

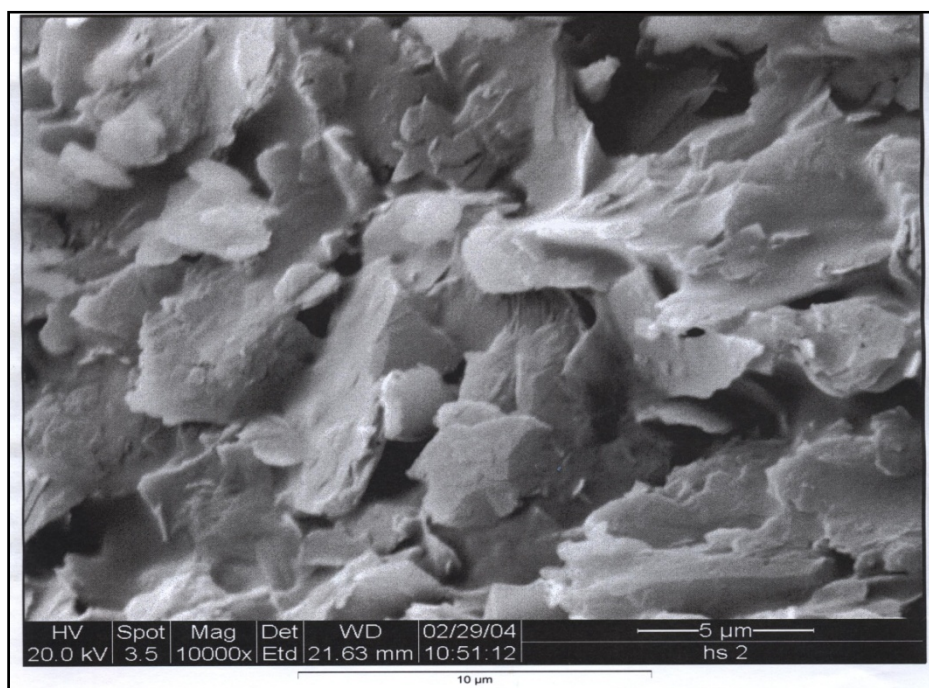


semi-arid climate with marked dry and wet

seasons (Khoury, 2002).

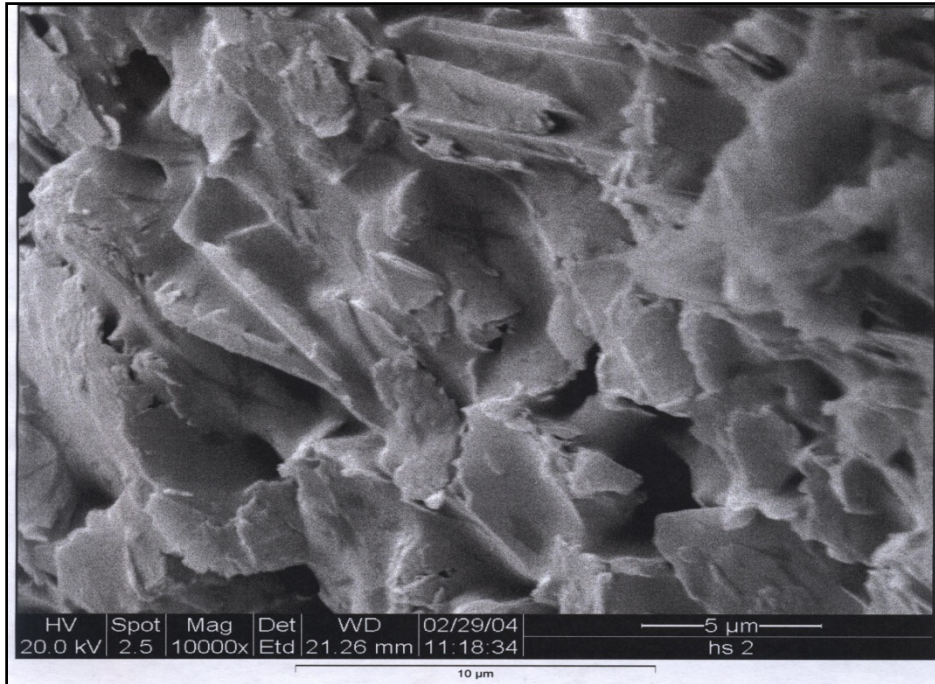


**Figure 7: X-ray diffractograms of the separated clay size fraction for untreated, glycolated and heated to 550°C, ordered sample from Wadi Unquiyya**

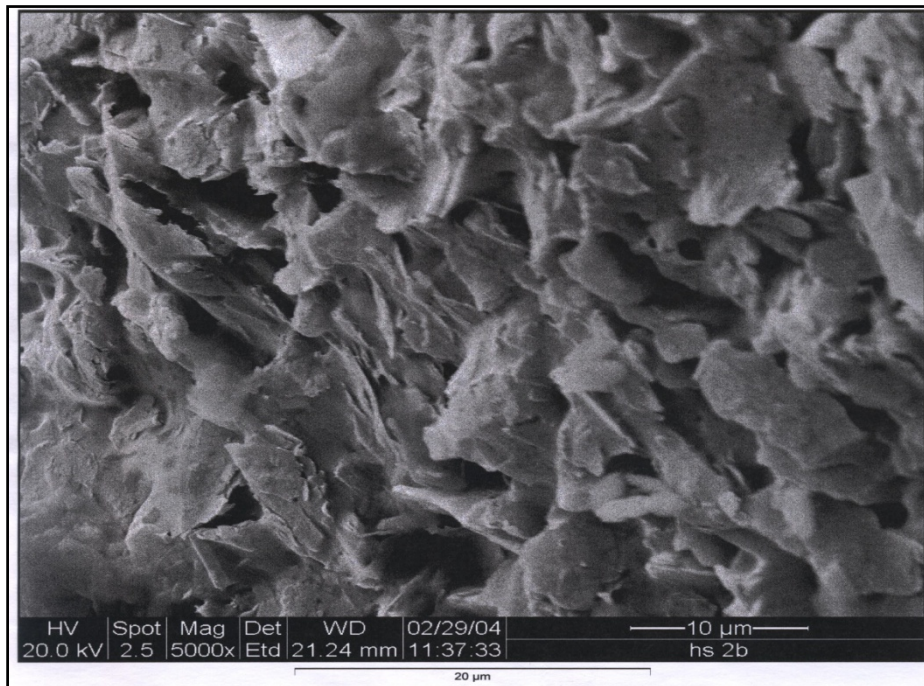


**Figure 8: Electron micrograph showing broken, unihedral crystals of kaolinite**





**Figure 9: Electron micrograph showing little fibers of palygorskite sprouting out from flakes of the mixed-layer of illite/smectite**



**Figure 10: Electron micrograph showing separated flakes and plates of the mixed-layer illite/smectite; the continuous growth of the mixed layer is absent**

**Table 1. Qualitative mineralogical composition of the selected samples analyzed by XRD, in the random, glycolated and heated slides**

Type of sample	Sample no.	Gypsum (Gyp)	Calcite (C)	Quartz (Q)	Feldspar (F)	Palygorskite (P)	Kaolinite (K)	Illite/smectite (I/S)
Random	Tal 1	N. D.	A	C	R	N. D.	N. D.	
	Tal 2	N. D.	A	A	C	R	R	
	Tal 3	N. D.	A	C	C	R	N. D.	
	Wun 2	N. D.	A	C	R	R	N. D.	
	Wun 3	N. D.	A	A	C	R	N. D.	
	Wun 4	C	A	C	C	R	N. D.	
	WHA 1	N. D.	A	C	C	R	N. D.	
Normal	WAH	C	C	C	C	A	A	C
	Tal	N. D.	N. D.	C	R	A	A	C
	WUN	N. D.	N. D.	C	R	C	A	C
Glycolated	WAH	N. D.	C	C	C	A	A	R
	Tal	N. D.	N. D.	C	C	A	A	R
	WUN	N. D.	N. D.	R	C	A	A	R
Heated to 550°C	WAH	N. D.	C	N. D.	N. D.	C	N. D.	N. D.
	Tal	N. D.	C	N. D.	N. D.	C	N. D.	N. D.
	WUN	N. D.	C	N. D.	N. D.	C	N. D.	N. D.
A: abundant		C: Common		R: Rare		N. D.: Not Detected		
Tal = Tal Aseikhem (pit 3)		Wun = Wadi Unquiyya (pit 1)		WHA = Wadi Hassan (pit 2)				

In Jordan, especially in Al-Azraq Playa, many researchers (Nawasrehm et al., 2006; Malak, 1995; Alali and Abu Salah, 1993; Quadan, 1992; Alali, 1991; Faraj, 1988; Khoury, 2002 and 1980) indicated that palygorskite formed authigenically by a direct chemical process of precipitation and by the transformation from smectite mineral to an environment rich in Mg/Si ratio.

However, this work, especially the SEM result, shows the source of the ions of palygorskite in this area which were produced by a chemical weathering process of the detrital material and transported. This is clear from the habit of palygorskite. No laths and fibers were seen, in spite of their preference in the samples which is detected by the X-ray method. It seems that the crystals were broken down during transportation of palygorskite.

3- The mixed layer of illite/smectite is also believed to be of detrital origin. It shows separated flakes of this mineral without continuous growth

indicating a detrital origin.

4- Within the soil in the study area, the formation of gypsum is restricted to the evaporation environment in the area depression (Khoury, 2002).

## CONCLUSION

Bearing in mind the nature of soil, most of the soil found in the topmost of this area is basically detrital, and its accumulation is undoubtedly linked to the deflation from the surrounding area. Clay minerals are also of detrital origin, and it is believed that the clay was formed by the mechanism of wind blowing. No variation in the distribution of the clay minerals was observed along the pits. Transitional phases as the appearance and disappearance of the minerals were also not observed, which enhances the concept of their detrital origin.

### ACKNOWLEDGEMENTS

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