*J. King Saud Univ*., Vol. 19, *Agric. Sci.* (1), pp. 25-38, Riyadh (1427H./2006)

# Characteristics of Natural Clay Deposits in Saudi Arabia and Their Potential Use for Nutrients and Water Conservation

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(Received 16/2/1426H.; accepted for publication 16/1/1427H.)

**Abstract.** Clay minerals in soils are the key component controlling water storage and movement in irrigated arid lands. Previous studies proved that the application of high quality clay minerals even in low quantities to coarse textured desert soils improved dramatically the water conservation and water use efficiency. The main objective of this research was to identify and characterize clay deposits and their desired characteristics for water conservation and source of nutrients. Forty-seven representative clay deposit samples were collected from different regions of Saudi Arabia. Samples were subjected to physical, chemical, nutrient status and mineralogical characterization. Results indicated that most of the selected sites were rich in natural clays, some were found at the surface while others were exposed in the slopes of the mountainous areas. Data showed relatively high variations in the clay deposit characteristics, particularly in clay contents, salinity, alkalinity and the dominant clay minerals. Smectite clays dominated the clay fraction of deposits collected from Khulays, Jeddah, Al-Hassa and Al-Kharj areas beside attapulgite, kaolinite and other minerals. Dhruma and Rawdat deposits were dominated mostly by kaolinite, illite and smectites. The characteristics of the studied clay deposits as follows: clay content (20-96%), saturation percentage (29-184%), field capacity (14-140%), wilting point (6-64%), available water content (8-77%), ECe dS/m (0.66-47.0), pH (6.82-8.36), $CaCO_3$ (1-52.9%) and CEC cmole/kg (10.3-77.2). It appears that samples with high clay contents have high available water and field capacity. Soluble B was relatively high in some samples collected from Al-Kharj. Nutrient status indicated that available Fe was very high in all samples while other nutrients (K, Mn, Zn and Cu) were high to moderate. Total heavy metals (Cd, Ni, Pb and Co) were low to moderate in most of the studied samples and relatively high in few samples, particularly that collected from the western region. Free Fe oxide ($Fe_d$) was the dominant component of the amorphous and free oxides. Amorphous Si and Al were quite variable, Dhruma-Marrat clays contain relatively high $Al_{am}$ than $Si_{am}$ other clays have mostly high $Si_{am}$ than $Al_{am}$. The presence of oxides and amorphous materials of Fe, Si and Al plays a major role for nutrient retention and water holding.

## Introduction

Saudi Arabia is geologically divided into four distinct and extensive terrains [1]. These are the Proterozoic Arabian Shield, comprising metamorphosed volcano sedimentary successions intruded by granite and gabbros; Arabian platform dipping gently eastward;

the Tertiary 'harrats' mainly overlying the Shield; and the narrow Red Sea coastal plain of Tertiary and Quaternary sedimentary rocks and coral reefs. According to Laurent favorable geologic conditions for the formation and accumulation of clay deposits are found in the following formations [1], Khuff, Marrat, Dhruma, Biyadh Sandstone, Wasia, Aruma, Hadrukh & Dam and some Paleogene-Neogene layers along the Red Sea. In most cases, the clay occurrences contain a predominant proportion of kaolinite. Exceptions are the distinctly marine deposits of the early Paleozoic (Jauf and Tauk formations) and the Tertiary littoral marine deposits of the east coast (Hadrukh and Dam formations) in which illite predominates. Certain lagoon or lacustrine environments generated deposits of attapulgite clay (Aruma and Dammam formations) or montmorillonitic clay (Tertiary formations of the Red Sea coast) [1]. Argiclays is essentially composed of argillaceous crystalline hydrous aluminum silicates containing Na, K and Ca in which Mg and Fe may be substituted for Al. Natural clays such as clay stone or mudstone comprise several clay minerals with one or more impurities. The most common impurities are free iron oxide minerals, amorphous silica and alumina, quartz grain, limestone, gypsum and other more soluble salts. These impurities affect largely clay characteristics and may affect adversely its use in specific applications. Lee *et al.* reported that clay mineralogical composition of soils along the eastern coastal playa near Al-Qatif is mostly smectite [2]. They added that palygorskite mineral is widely distributed in the eastern region soils which originated from the underlying Mio-Pliocene limestone in the basin, and to be redistributed by alluvial and aeolian processes. There have been studies on the use of natural deposits to alleviate some of the soil constraints to its production [3, 4]. Afifi reported that the addition of bentonite to sandy soil increased retention and availability of soil moisture as well as cohesive forces among their particles [5]. He concluded that the addition of bentonite reduced the velocity of downward water movement and restricted deep percolation and leaching nutrients. Das and Dakshinamurti showed that the infiltration rate and hydraulic conductivity of sandy loam soils treated with bentonite were reduced compared to untreated soils [6]. They concluded that infiltrations as well as the diffusivity were very much reduced in the treated soils. Therefore, the main objective of this research was to characterize natural clay sediments from different regions in Saudi Arabia in order to evaluate their potential use as natural amendments and source of nutrients.

## Material and Methods

Forty-seven representative samples were collected from selected clay deposits located in different regions in Saudi Arabia. The selection of the sites was based on previous geological studies, e.g. [1]. Collected samples were prepared for mineralogical, physical and chemical analyses following the standard procedures. Field capacity at 33 kPa (FC), permanent welting point at 1500 kPa (WP) and available water (Aw) contents (FC-WP) of the collected sediments were determined according to the methods described by [7]. Particle size distribution was carried out using the international pipette method. Saturation water percentage (SP %) was determined gravimetrically. Soluble salts were measured electrometrically using EC meter in the saturation paste extract while pH was measured in the same extract using pH meter. Calcium carbonate content was determined according to [8]. Organic matter content was determined spectophotometrically according to [9]. Cation exchange capacity (CEC) was determined according to the method described by [10]. The surface area was determined according to BET method described by [11]. Representative sub-samples were extracted by DTPA (Di Tetra Penta Amine Acetic Acid) according to [12] for available micronutrients determinations. Extractable Fe, Mn and Zn were measured using atomic absorption spectrometry (AAS) according to [13]. Available phosphorus was determined by the modified $NaHCO_3$ method using ascorbic acid as a reducing agent [14]. The total elemental analysis was carried out after sample digestion using hydrofluoric acid in a closed vessel as described by [15]. Total Fe, Mn, Co, Cd, Zn, Ni and Pb were measured in the acid extracts using AAS. Total K was measured using flame photometer while total P was measured in the same extract spectrophotometrically. Clay fraction (<2 um) was separated according to [15]. Sub-samples of clay fraction were Mg or K saturated using 1M $MgCl_2$ or 1M KCl, respectively, then slides were prepared as oriented mounts. X-ray diffractograms were obtained using Cu-Kα radiation at 40 kV and 25 mA. K-saturated samples were scanned after air drying and following heat treatment at 550$^o$C for 2 hours. Mg-saturated samples were scanned following air drying and ethylene glycol solvation. The identification of clay minerals and accessory minerals was carried out according to [16]. Free iron and manganese oxides ($Fe_d$ & $Mn_d$) were extracted using sodium citrate bicarbonate-dithionate method (CBD) according to [17]. Amorphous silica and alumina ($Si_{am}$ & $Al_{am}$) were dissolved in boiled NaOH (1N) for 2.5 minutes according to [18] then Al and Si in the extracts were measured by AAS as described by [13].

## Results and Discussion

Samples collected from Dhruma (Nos. 1-7) (Table 1) were characterized by the presence of deep and massive clayey layers having different colors, thickness and compositions. Al-Kharj sites sample Nos. 8-18; 35-39 and 45-46 were located on the eastern platform and consist of isolated hills where clay and sand exposed on gentle slopes beneath the limestone. These layers contain massive compacted clays in some sites while other sites contain friable clayey layers in the form of fractured mud stone having different colors. Jeddah–Khulays sites (Nos. 19-33) contain widespread thick clayey layers having different colors and were mostly compacted to friable. Clay layers in most of the studied locations are exposed intermittently on gentle slopes beneath the stony layers on the surface. Al-Rawdat sediments (Nos. 34, 40 and 44) are found in the nearly level surfaces in the depressions and contain very thick deposits carried out from the surrounding hills and mountains. It has cracked surface particularly during the dried periods.

### Physical and chemical properties

Table 2 showed that the studied sediment has clay content ranges from 18.0-96.0% with the mean of 54.8% clay. Very high clay content was recorded in Al-Hassa sites (Nos. 35 and 36). All the studied samples are clayey texture, with some exceptions. Cation exchange capacity values (CEC) was quite high in most of the studied samples

**Table 1. Location, sample description and relevant characteristics of the collected sediment samples**

| No. | Location | Color, dry | EC dS/m | Soluble B mg/kg | $CaCO_3$ % | Clay % | Description |
|---|---|---|---|---|---|---|---|
| | | | | **Middle Region** | | | |
| 1 | Dhurma | 2.5YR5/4 | 10.7 | 1.31 | 3.0 | 78 | Thick, flocculated clay |
| 2 | Dhurma | 7.5YR6/4 | 7.15 | 2.59 | 3.0 | 60 | Thick un-compacted layer |
| 3 | Dhurma | 7.5YR5/4 | 10.26 | 7.57 | 3.0 | 74 | Thick layer, compacted |
| 4 | Dhurma | 7.5YR5/4 | 25.1 | 4.67 | 22.0 | 48 | Non-compacted clay |
| 5 | Dhurma | 10YR7/2 | 6.2 | 0.76 | 4.0 | 84 | Olive layer between red clays |
| 6 | Dhurma | 7.5YR6/4 | 7.13 | 0.93 | 3.0 | 84 | Fine clay, grind |
| 7 | Dhurma | 7.5YR6/4 | 8.47 | 0.93 | 3.0 | 48 | Layer of thick mud clay |
| 8 | Al-Kharj | 2.5Y7/4 | 47.6 | 6.87 | 3.0 | 68 | Mottled mud clayey layers |
| 9 | Al-Kharj | 10YR7/4 | 28.2 | 2.85 | 3.0 | 66 | Blocky, compacted clay layer |
| 10 | Al-Kharj | 5YR7/4 | 8.83 | 1.02 | 5.0 | 66 | Colored friable clayey layer |
| 11 | Al-Kharj | 5YR7/3 | 11.28 | 1.46 | 1.0 | 60 | Clayey, friable layer |
| 12 | Al-Kharj | 5YR5/6 | 7.0 | 2.55 | 2.0 | 56 | Granulated, compacted layer |
| 13 | Al-Kharj | 2.5Y7/8 | 21.0 | 11.79 | 10.0 | 44 | Mud stones with cement |
| 14 | Al-Kharj | 10YR7/6 | 10.62 | 11.4 | 42.0 | 36 | Clay, friable, not compacted |
| 15 | Al-Kharj | 10YR7/6 | 12.52 | 11.4 | 35.0 | 48 | Clay layers, thin gypsum layers |
| 16 | Al-Kharj | 10YR6/3 | 34.0 | 11.79 | 4.0 | 48 | Thick clayey layers, compacted |
| 17 | Al-Kharj | 2.5Y7/8 | 15.3 | 10.45 | 39.0 | 48 | Layers, compacted clays, friable |
| 18 | Al-Kharj | 10YR7/2 | 15.3 | 3.79 | 4.0 | 20 | Compacted, disconnected clay |
| 34 | Rawdat | 10YR7/3 | 3.35 | 0.74 | 42.0 | 59 | Cracked flat surface, sticky clay |
| 43 | R-Kharj | 2.5Y 7/6 | 19.5 | - | 29.6 | 57 | Thick clayey layers, very sticky |
| 44 | Al-Summan | 10YR 7/3 | 0.66 | - | 34.4 | 81 | Cracked flat surface, sticky clay |
| 47 | Sudir | 2.5Y 7/6 | 27.0 | - | 21.1 | 53 | Compacted, mottled, sticky clay |

**Table 1.** *Contd.*

| No. | Location | Color, dry | EC dS/m | Soluble B mg/kg | $CaCO_3$ % | Clay % | Description |
|---|---|---|---|---|---|---|---|
| | | | | **Western Region** | | | |
| 19 | Jeddah | 10YR8/1 | 22.8 | 5.59 | 16.0 | 32 | Cemented, disconnected f |
| 20 | Jeddah | 5YR5/4 | 22.9 | 3.44 | 1.0 | 48 | Thick sticky clayey layer |
| 21 | Jeddah | 2.5YR4/6 | 38.9 | 4.29 | 7.0 | 84 | Very thick sticky clayey |
| 22 | Jeddah | 5YR7/3 | 6.47 | 3.13 | 4.0 | 28 | Layers of compacted white clay |
| 23 | Khulays | 2.5YR5/6 | 19.4 | 6.62 | 13.0 | 44 | Thick compacted red clays |
| 24 | Khulays | 10YR5/8 | 7.6 | 5.25 | 5.0 | 52 | Thin layer, gully erosion |
| 25 | Khulays | 5Y8/2 | 22.7 | 5.96 | 3.0 | 56 | Clods of mud, friable, fine |
| 26 | Khulays | 5Y8/2 | 21.0 | 7.28 | 14.0 | 24 | Clods of mud, friable, fine |
| 27 | Khulays | 5YR5/6 | 22.0 | 4.92 | 3.0 | 60 | Clayey clods, red, compacted |
| 28 | Khulays | 2.5Y7/8 | 52.2 | 6.87 | 3.0 | 28 | Clayey clods, red, compacted |
| 29 | Khulays | 10YR8/1 | 31.0 | 3.59 | 3.0 | 60 | Clay clods, compacted, mottled |
| 30 | Khulays | 2.5Y7/2 | 40.8 | 5.18 | 5.0 | 60 | Clayey clods, red, compacted |
| 31 | Khulays | 5Y7/3 | 12.38 | 3.74 | 5.0 | 68 | Fine clods in cracks |
| 32 | Khulays | 5YR4/6 | 5.48 | 1.56 | 5.0 | 32 | Very fine clayey clods, sticky |
| 33 | Khulays | 5YR5/4 | 12.06 | 1.05 | 3.0 | 48 | Very fine clayey clods, very sticky |
| 41 | Madinah 1 | 10YR7/4 | 2.35 | - | 9.3 | 61 | Thick clayey layers, very sticky |
| 42 | Madinah 2 | 2.5Y6/2 | 1.9 | - | 4.9 | 18 | Thick clayey layers, very sticky |
| | | | | **Eastern Region** | | | |
| 35 | Al-Hassa | 5Y7/2 | 12.09 | 3.31 | 3.0 | 96 | Compacted clayey thick layers |
| 36 | Al-Hassa | 5Y7/2 | 6.44 | 1.31 | 5.0 | 96 | Compacted very sticky clay layers |
| 37 | Al-Hassa | 5Y7/2 | 13.5 | 3.01 | 2.0 | 86 | Compacted sticky clayey layers |
| 38 | Al-Hassa | 5Y7/2 | 47.0 | 2.02 | 19.0 | 51 | Compacted clayey thick layers |
| 39 | Al-Hassa | 5Y 8/2 | 22.5 | 2.08 | 28.0 | 27 | Compacted clayey thick layers |
| 45 | Al-Hassa | 10YR 8/2 | 35.0 | - | 56.0 | 20 | Compacted, clayey layers |
| 46 | Al-Hassa | 10YR 8/2 | 19.5 | - | 52.9 | 46 | Compacted, friable clay |
| | | | | **Northern Region** | | | |
| 40 | Hail | 10YR7/4 | 19.0 | - | 10.4 | 65 | Friable thick clayey layers |

and ranged from 8.4 to 77.2 cmole $kg^{-1}$. High CEC values correspond to the high clay content in most of the studied samples. High CEC values and clay contents are considered one of the favorable characteristics that reflect the positive sign for increasing water storage capacity of the sediment sample. $CaCO_3$ contents range from 1.0 to 56.0 g $kg^{-1}$. Low calcium carbonate contents were mostly found in the samples collected from Dhruma, Jeddah-Khulays areas and some locations of Al-Kharj. Rawdat and Al-Hassa samples (Nos. 45 and 46) have relatively high $CaCO_3$ contents. High carbonate contents in the natural sediments may be considered one of the constraints for their use as soil amendments in arid lands mostly because of their unfavorable physicochemical properties toward nutrient precipitation in the soil. Salinity levels in the studied sediments (Table 2) are quite variable and range from 0.66-52.2 $dSm^{-1}$. Rawdat sample, most of western region samples and some of the eastern region samples have relatively low salt contents due to the leaching effects caused by deep percolation of rain water [19]. High salt contents in the sediment samples are one of the major constraints for sediment applications to sandy soils due to their possible effects on the increase of soluble salts in the soil.

On the other hand, methods of sediment applications and the appropriate soil and water management practices can control the undesired effects of the applied sediments and salts to sandy soil [4]. Values of sediment's pH ranged from 6.82 to 8.36, which corresponded to most of the arid soils. Data of water soluble B (Table 1) in the saturation paste extract are variable and range from 0.74–11.79 ppm. The highest values were found in some samples of Al-Kharj (No. 13 to No. 17), while most of the studied samples, particularly Dhruma sediments, were quite low in soluble B. Such high B values may not be that critical from the toxicity viewpoint taking into account the quantity of applied sediments and the methods of sediments application. The data in Table 2 indicated also that the studied sediments have relatively high contents of total Fe particularly in the sediment samples from Al-Madinah (Nos. 41 and 42) 132.5 $gkg^{-1}$ where the sediments were formed from the basaltic lava of the Harrat which dominated most of the formations in the area. The lowest content was found in the clayey samples collected from Al-Hassa. Total $K_2O$ and $P_2O_5$ are quite variable and range from 0.10-23.2 and 0.01-16.9 $gkg^{-1}$ respectively. Dhruma, Al-Kharj and Khulays samples have relatively high contents of total K while samples collected from Al-Madinah and many samples from Khulays and Al-Kharj have relatively high contents of total $P_2O_5$. Total contents of heavy metals, i.e. Cd, Pb, Ni, Co, Zn and Mn in all the studied sediments are highly variable (Table 2). Most of the collected samples have low contents of total heavy metals and are below the maximum allowable limits (MAL) for heavy metals in soils used in different countries [20]. Total Cd ranges from 1.5-5.53 mg $kg^{-1}$ with the mean at 2.45 mg $kg^{-1}$ and (STD 1.06). Only three samples from Al-Hassa and Sudiar have values above MAL at 5 mg $kg^{-1}$. Total Co was far below (MAL) in all the collected samples. Total Ni was mostly below M.A.L. value (100 mg $kg^{-1}$) except one sample from Khulays (No. 34) and one sample from Al-Summan (No. 44). Total Ni ranges from 2.30-130 mg $kg^{-1}$. Total Pb content was low (< 35 mg $kg^{-1}$) in all the collected samples from Dhurma, Khulays and Al-Kharj while few samples from Al-Hassa, Al-Madenah and Hail have

**Table 2. Means, maximum, minimum and standard deviation (STD) values of sediment characteristics for all the collected sediments**

| Characteristic | Mean | Minimum | Maximum | STD |
|---|---|---|---|---|
| **Moisture characteristics (30 samples)** | | | | |
| Saturation % | 80.77 | 29.0 | 184 | 36.54 |
| Field Capacity % | 58.6 | 14.0 | 140 | 27.55 |
| Welting point % | 25.67 | 6.0 | 64 | 13.87 |
| Available water % | 32.93 | 8.0 | 77 | 15.81 |
| **Some physical and chemical characteristics (47 samples)** | | | | |
| Clay % | 54.80 | 18.0 | 96.0 | 20.01 |
| Silt % | 20.60 | 2.00 | 56.0 | 12.04 |
| $CaCO_3$ % | 12.70 | 1.00 | 56.0 | 14.82 |
| ECe dS $m^{-1}$ | 18.50 | 0.66 | 52.2 | - |
| CEC Cmole $kg^{-1}$ | 31.70 | 8.39 | 77.2 | 18.44 |
| $Fe_2O_3$ d $gkg^{-1}$ | 24.09 | 2.13 | 61.62 | - |
| $MnO_2$ d $gkg^{-1}$ | 0.60 | 0.008 | 3.587 | - |
| **Total elemental and heavy metal contents (47 samples)** | | | | |
| $Fe_2O_3$ (g $kg^{-1}$) | 57.8 | 6.20 | 132.5 | 29.6 |
| $K_2O$ (g $kg^{-1}$) | 4.72 | 0.10 | 23.2 | 4.98 |
| $P_2O_5$ (g $kg^{-1}$) | 2.12 | 0.01 | 16.9 | 2.67 |
| Cd (mg $kg^{-1}$) | 2.54 | 1.50 | 5.53 | 1.06 |
| Pb (mg $kg^{-1}$) | 47.04 | 14.0 | 455.0 | 71.74 |
| Ni (mg $kg^{-1}$) | 49.56 | 2.3 | 130.0 | 24.63 |
| Co (mg $kg^{-1}$) | 17.62 | 2.0 | 36.0 | 10.13 |
| Zn (mg $kg^{-1}$) | 155.3 | 11.0 | 1421.0 | 272.0 |
| Mn (mg $kg^{-1}$) | 393.3 | 14.0 | 3859.0 | 659.6 |
| **Available nutrient levels (47 samples)** | | | | |
| $P_2O_5$ (mg $kg^{-1}$) | 3.11 | 0.01 | 21.4 | 3.15 |
| Zn (mg $kg^{-1}$) | 3.56 | 0.25 | 35.8 | 6.06 |
| Mn (mg $kg^{-1}$) | 6.01 | 0.14 | 53.8 | 10.69 |
| Fe (mg $kg^{-1}$) | 25.6 | 0.70 | 280.0 | 45.7 |

relatively high total Pb>100 mg $kg^{-1}$. Samples Nos. 43 and 44 have very high total Pb content which could be due to Pb pollution caused by the heavy traffic on the Kharj-Riyadh highway where the sample was taken. Total Zn content was low (<100 mg $kg^{-1}$) in most of the collected samples and show high (about 300 mg $kg^{-1}$) to very high (> 400 mg $kg^{-1}$) contents in the samples collected from Al-Hassa, Al-Madenah and Hail.

Correlation coefficients between some soil characteristics and moisture parameters showed positive correlations data (Table 3) between sediment moisture parameters (i.e. FC, WP, SP and AW) and sediment characteristics (i.e. clay content, silt content, $CaCO_3$ and CEC). It indicated significant positive correlation between all moisture constants and either clay content or CEC. On the other hand, $CaCO_3$ content show negative non-significant correlation with sediments moisture constants.

**Table 3. Correlation coefficient data between sediment moisture characteristics and relevant sediment properties**

| Sediment properties | Moisture characteristics | | | |
|---|---|---|---|---|
| | SP % | FC %. | WP % | AW % |
| Clay content % | 0.491 | 0.449 | 0.542 | 0.321 |
| Silt content % | 0.158 | 0.076 | 0.123 | 0.026 |
| CEC cmole $kg^{-1}$ | 0.682 | 0.752 | 0.833 | 0.605 |
| $CaCO_3$ | - 0.082 | - 0.024 | - 0.089 | 0.039 |

SP: Saturation Percentage, FC: Field Capacity, WP: Wilting Point, AW: Available Water.

## Moisture characteristics

A moisture characteristic is the main desired property that was used to evaluate the importance of sediment for water conservations in sandy soils. Table 2 showed that the saturation water percentages (SP %) were greatly variable and ranged from 29-184% with an average of 80.8% and STD of 36.45. High SP was corresponding with high clay content in most of the studied samples. Al-Hassa sediment samples (Nos. 35-37) as well as many samples from Khulays (Nos. 23, 24 and 29), Al-Kharj (Nos. 8-10), Dhruma (No. 3) and Sudir (No. 47) show high SP values. Data also indicated that field capacity (FC) and wilting point (WP) values of all the studied samples have relatively high values particularly those with high clay content. On the other hand, available water contents are high and reach about 76% which was quite high. In addition, the sediments having high saturation percentage and other moisture characteristics to sandy soil will improve soil water holding capacity and eliminate deep percolation of irrigation water and hence improve water conservation in such soils [4].

## Available nutrient status

The data in Table 2 include ranges, means and standard deviation values of nutrient status of the collected samples. It was used for the interpretation of nutrient status in the studied sediments according to the guidelines reported by [21, 22]. It indicated that most of the studied sediments have low contents of available P and few samples have high to very high contents of available P as the available P ranged from 0.01-21.4 $mgkg^{-1}$. Most of the studied sediments have low contents of available P and few samples have high to very high contents of available P. Available Fe show very high values in most of the studied samples, particularly in Rawdat, Al-Madinah and Khulays samples. It ranges from 0.70-280.0 $mgkg^{-1}$ which considered very high for Fe levels [21]. High available Fe could be expected in the sediments formed from igneous rocks rich in Fe–silicates, particularly those formed in Jeddah and Khulays areas. Weathering processes for Ferro-magnesium minerals under the existing and past climatic conditions were responsible for the formation of Fe-rich clay deposits and the accessory minerals mainly iron oxides. Weathering products of Fe-bearing minerals are considered the main sources for available Fe and other micronutrients in the sediments as well as for the retention of nutrient cations in readily available form. Zn levels ranges from 0.25-35.80 mg $kg^{-1}$ which was very high. High available Zn was recorded in sediment samples collected from many locations at Al-Kharj, Al-Madinah, Sudir, Rawdat and Al-Hassa. A very high content of available Mn was also recorded in Al-Summan sample (No. 44), Rawdat (No. 34), Hail (No. 40) and Al-Madinah samples. Available Mn ranges from 0.14 to 53.8 mg $kg^{-1}$ which considered also very high according to [21]. It seems from these data that most of the collected sediment samples contain relatively high contents of the available micronutrients Fe, Mn and Zn. Such high levels of micronutrients will improve the content of these nutrients when applied to micronutrient deficient sandy soils.

**Mineralogical characteristics**

The data in Table 2 indicated also that free Fe oxides ($Fe_2O_3$d) ranged from 2.13-61.62 g $kg^{-1}$. The highest contents were observed in Dhruma and Khulays samples (data not shown), while Al-Hassa and some samples from Jeddah area have relatively low amounts. Free Mn oxides ($MnO_2$d) showed relatively low quantities which ranged from 0.008-3.59 g $kg^{-1}$ with quite similar trend except that high quantities were observed in Khulays and Jeddah samples which could reflect the mineralogical composition of the dominant igneous and metamorphic rocks from which these deposits were formed. The presence of oxides in relatively high quantity reflects the high potential for anion adsorption and retention of metals [23].

Separated clay fraction was characterized using X-ray diffraction and the selective chemical techniques for amorphous Si & Al and free Fe & Mn oxides determination. The surface area and CEC was also measured in selected samples and presented in Table 4. Data indicated that CEC values were quite high, particularly in most of the high clay samples. It ranges from 32.05–93.8 cmole/kg. Most of the studied clays have high surface area; it ranges from 66.3-371.4 $m^2$/gm which was quite high and reflect the high reactivity of clay fraction with respect to water retention and ion exchange if it was added to low surface area's sandy soil. The highest values were found in the clay fraction separated from Dhruma samples (Nos. 7 and 8), while the lowest was found in clay fraction of Al-Madinah (No. 42). Amounts of free Fe oxides ($Fe_d$) are the dominant component of the amorphous and free oxides while $Mn_d$ was relatively very low. Data of amorphous Si and Al in the clay fraction are quite variable between the studied samples of the different locations. It appears that most of Dhruma-Marrat clays contain relatively high $Al_{am}$ than $Si_{am}$ compared with clays from other regions which mostly contain high $Si_{am}$ than $Al_{am}$. The presence of oxides and amorphous materials of Fe, Si and Al play a major role for nutrient retention and water holding because it was present mostly in the colloidal phase with high surface area and greater reactivity towards anion adsorption than the corresponding crystalline mineral phases [23].

**Table 4. Amorphous Si and Al, Free Fe and Mn oxides, surface area and cation exchange capacity (CEC) of clays separated from sediment samples**

| No. | CEC Cmole $kg^{-1}$ | Surface area $m^2$ $gm^{-1}$ | $Al_{am}$ | $Si_{am}$ | $Fe_d$ | $Mn_d$ |
|---|---|---|---|---|---|---|
| | | | g/kg | | | ppm |
| 3 | 34.75 | - | 0.73 | 1.18 | 7.90 | 24.0 |
| 4 | 52.72 | - | 2.15 | 1.49 | 19.30 | 58.6 |
| 7 | 73.91 | 318.9 | 2.82 | 0.83 | 15.52 | 60.8 |
| 8 | 93.80 | 371.4 | 3.96 | 1.01 | 11.07 | 39.1 |
| 9 | 34.38 | 150.0 | 0.08 | 0.86 | 3.68 | 16.7 |
| 10 | 78.24 | - | 2.84 | 0.87 | 24.99 | 155.8 |
| 12 | 44.03 | - | 0.45 | 0.76 | 1.19 | 5.66 |
| 13 | 71.28 | 327.9 | 1.32 | 1.12 | 5.62 | 24.2 |
| 14 | 84.06 | - | 4.06 | 1.53 | 8.54 | 21.0 |
| 16 | 78.73 | - | 1.75 | 1.72 | 16.24 | 87.5 |
| 17 | 48.89 | 240.3 | 0.45 | 1.51 | 14.88 | 47.1 |
| 18 | 88.98 | - | 0.27 | 0.85 | 4.37 | 376.2 |
| 19 | 62.33 | 252.1 | 0.42 | 2.13 | 11.11 | 987.2 |
| 20 | 33.48 | 95.4 | 0.47 | 1.04 | 9.47 | 42.8 |
| 21 | 39.25 | 149.3 | 0.68 | 0.61 | 29.21 | 73.6 |
| 24 | 61.95 | - | 0.31 | 0.42 | 13.55 | 335.7 |
| 25 | 80.2 | 341.1 | 0.24 | 0.96 | 7.57 | 41.4 |
| 26 | 80.89 | - | 0.34 | 1.41 | 3.38 | 14.0 |
| 27 | 56.04 | 128.4 | 0.98 | 1.34 | 25.99 | 131.4 |
| 28 | - | 273.8 | - | - | - | - |
| 29 | 55.55 | 201.2 | 0.30 | 1.75 | 1.15 | 5.85 |
| 30 | 74.76 | 206.3 | 0.34 | 0.96 | 5.92 | 47.2 |
| 31 | 76.43 | 190.8 | 0.26 | 0.95 | 4.77 | 4.8 |
| 32 | 54.38 | - | 0.38 | 0.64 | 18.82 | 151.3 |
| 33 | 65.43 | - | 0.73 | 1.00 | 20.14 | 187.1 |
| 34 | 45.58 | 149.9 | 1.00 | 2.88 | 9.61 | 164.8 |
| 35 | 56.87 | 224.8 | - | - | - | - |
| 36 | 61.65 | 254.4 | - | - | - | - |
| 37 | - | 110.4 | - | - | - | - |
| 38 | 32.05 | 207.5 | - | - | - | - |
| 39 | - | 118.7 | - | - | - | - |
| 40 | 46.68 | 198.2 | - | - | - | - |
| 41 | 56.54 | 149.6 | 0.80 | 1.92 | 9.71 | 156.64 |
| 42 | - | 66.3 | - | - | - | - |
| 43 | - | 109.1 | - | - | - | - |
| 44 | 46.85 | 288.5 | 0.53 | 1.41 | 10.17 | 67.59 |

$Al_{am}$: amorphous alumina, $Si_{am}$: amorphous silica, $Fe_d$: free Fe oxides, $Mn_d$: free Mn oxides.

Semi-quantitative mineralogical composition of clay fraction separated from sediment samples were determined from the obtained X-ray diffractograms of the studied sediments and figured out in Table 5. Sediment samples from Dhruma and Al-Kharj are dominated by either smectite or kaolinite with no palygorskite exists except few samples. It was noticed that most of the obtained variation was related to the location in the mining area from which the sample was taken. For example, at Dhruma site, one sample was dominated by smectite (sample No. 5 collected from the grayish layer in the mining area), while the other samples in the site were dominated by kaolinite (Nos. 3 and 4 other layers in the same mining site). The data also indicated the dominance of smectit clays in most of the collected samples from Khulays and Jeddah area (i.e. samples Nos. 19, 22, 23 and 27). Samples No. 35 and 36 were dominated mainly by smectite clays followed by illite and vermiculte. Clay fraction separated from Harrat Al-Madinah was dominated by smectite followed by kaolinite and chlorite while Sudir and Al-Hassa clays were dominated by palygorskite followed by smectite and interstratified minerals. The dominance of smectite type clays in the sediment samples is considered a positive indication for increasing water holding capacity of the sediment as well as increasing nutrient retention against leaching and losses in sandy soils.

## Conclusion

The identification of natural clay sediments from different regions in Saudi Arabia indicated that clay content ranges from 18.0-96.0% with the mean of 54.8% clay. CEC was high and ranges from 8.4 to 77.2 cmole $kg^{-1}$ with the mean of 31.7 cmole $kg^{-1}$. Salinity levels and $CaCO_3$ content range from low to high, higher values were considered the major constraints for sediment applications to sandy soils. Most of the sediments have low contents of total heavy metals (Co, Cd, Ni and Pb) which are below the maximum allowable limits (MAL) for heavy metals in soils. Available P was generaly low while available Fe, Zn and Mn was high to very high in most of the studied samples particularly in Al-Rawdat, Harrat and Khulays samples. High levels of micronutrients in many of the studied samples will improve the content of these nutrients when applied to micronutrient deficient sandy soils. Clay fraction show high CEC and surface area which reflect high reactivity with respect to water retention and ion exchange. $Fe_d$ was the dominant component of the amorphous and free oxides. Amorphous Si and Al are quite variable, Dhruma-Marrat clays contain relatively high $Al_{am}$ than $Si_{am}$ other clays have mostly high $Si_{am}$ than $Al_{am}$. The presence of oxides and amorphous materials of Fe, Si and Al plays a major role for nutrient retention and water holding. Sediment samples from Dhruma and Al-Kharj are dominated by either smectite or kaolinite smectit clays dominated the clay fraction of most samples from Khulays and Jeddah and Al-Madinah, while Sudir and Al-Hassa clays were dominated by palygorskite followed by smectite and interstratified minerals. The dominance of smectite type clays in the sediment samples is considered a positive indication for increasing water holding capacity of the sediment as well as increasing nutrient retention against leaching and losses in sandy soils.

**Table 5. Semi quantitative analysis of X-ray diffractograms obtained for clay fraction separated from sediment samples**

| No. | Smectite | Kaolinit | Palygorskite | Interstratified | Illite | Quartz | Others |
|---|---|---|---|---|---|---|---|
| 3 | ++ | ++++ | - | ++ | + | + | - |
| 4 | ++ | ++++ | - | + | + | + | - |
| 5 | ++++ | + | - | + | + | + | - |
| 6 | ++++ | ++ | + | - | + | + | - |
| 8 | +++ | +++ | - | + | + | + | - |
| 10 | ++++ | +++ | - | + | + | + | Fd. + |
| 15 | +++ | ++++ | - | - | + | + | - |
| 17 | +++ | + | + | + | - | + | - |
| 19 | +++ | + | + | - | + | ++ | Cal.+ |
| 21 | +++ | ++++ | - | - | + | + | - |
| 22 | ++++ | + | - | - | + | + | Fd+ |
| 23 | ++++ | ++ | + | - | + | - | Fd+ |
| 27 | ++++ | +++ | - | + | + | + | Cal+ |
| 34 | + | ++++ | + | + | + | + | Vr+ |
| 35 | ++++ | + | + | - | + | + | Vr+ |
| 36 | ++++ | + | + | - | ++ | + | Vr. T |
| 37 | ++ | + | ++ | T | + | ++ | Vr.T |
| 38 | ++ | + | ++ | ++ | + | T | Vr.+ |
| 40 | + | + | T | +++ | + | + | Vr.+ |
| 41 | +++ | ++ | T | - | + | + | Ch++ |
| 42 | +++ | ++ | T | - | + | + | Ch+ |
| 43 | ++ | +++ | - | - | + | - | Vr+ |
| 44 | + | +++ | ++ | - | - | T | Ch.+ |
| 45 | ++ | T | +++ | ++ | - | - | Vr+ |
| 46 | ++ | T | ++++ | ++ | + | + | Vr+ |
| 47 | ++ | - | ++++ | ++ | - | + | Vr+ |

++++ Dominant, +++ High, ++ medium, + low, T. traces, Fd. Feldspar, Vr. Vermiculite, Ch. Chlorite, Cal. Calcite.

***Acknowledgement.*** This article is a part of the project funded by King Abdulaziz City for Science and Technology No. AR-20-64 entitled "The Use of Natural Clay Deposits to Conserve Irrigation Water in Saudi Arabia".

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# خواص رواسب الط الطبيعية با ملكة العربية السعودية وإمكانيا ا ترشيد ا غذيات وا ياه

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(قدم للنشر في ١٤٢٦/٢/١٦هـ؛ وقبل للنشر في ١٤٢٧/١/١٦هـ)

**ملخص البحث.** تتحكم معادن الطين في التربة في حفظ الرطوبة وحركة الماء في ترب المناطق الجافة المروية. لقد أوضحت الدراسات السابقة بأن إضافة رواسب الطين ذات المحتوى الطيني العالي وبنسب منخفضة إلى الترب الرملية أدت إلى التحسن في المحافظة على الماء ورفع كفاءة استخدامه. يهدف هذا البحث إلى التعرف على أماكن وجود رواسب الطين الطبيعية في بعض المناطق بالمملكة العربية السعودية وتحديد أهم خواصها الفيزيائية والكيميائية والخصوبية والمعدنية. تم جمع ٤٧ عينة من مواقع مختلفة من مناطق المملكة وإعدادها للتحليلات المعملية المختلفة. أوضحت الدراسة أن معظم المواقع المختارة بها كميات كبيرة من رواسب الطين الطبقية والتي تتكشف في المنحدرات الجبلية. أوضحت النتائج وجود اختلافات كبيرة في خواص هذه الرواسب من المناطق المختلفة خاصة في نسبة ونوع الطين، وتركيز الأملاح الذائبة، والقلوية، ونسبة الجير ومحتواها من العناصر الغذائية الميسرة. تسود معادن السمكتيت مكون الطين في رواسب المنطقة الغربية (خليص، جدة) ورواسب بعض المناطق الأخرى (القطيف والخرج) بجانب معادن أخرى أهمها الكاؤلينيت في الأولى والأتابولجيت في الثانية، بينما تسود معادن الكاؤلينيت يليها الإليت والسمكتيت في رواسب ضرما وروضات المنطقة الوسطى. تراوحت عينات الرواسب في خواصها المختلفة حيث تراوح محتوى الطين بين ٢٠-٩٦٪، ودرجة التشبع بالماء بين ٢٩-١٨٤٪، والسعة الحقلية بين ١٤-١٤٠٪، ونقطة الذبول بين ٦-٦٤٪، والماء الميسر بين ٨-٧٧٪، وتركيز الأملاح ECe بين ٠,٦٦–٤٧ dS/m، وpH بين ٦,٨٢-٨,٣٦، و$CaCO_3$ بين ١-٥٢٪ ، والسعة التبادلية الكاتيونية بين ١٠,٣-٧٧,٢ cmole/kg. كان مستوى الحديد الميسر مرتفعا جدا في كل العينات، بينما كان مستوى عناصر K, Mn, Zn مرتفع إلى المتوسط في معظم العينات. أوضحت نتائج التحليل الكلي أن مستوى عناصر Co, Pb, Ni, Cd كان منخفضا إلى المتوسط عدا بعض العينات. يستنتج من هذه الدراسة أن رواسب الطين الطبيعية الغنية بمعادن السمكتيت والمرتفعة في محتواها من الطين والسعة التبادلية الكاتيونية ومستوى العناصر الغذائية الميسرة والماء الميسر تكون ذات قدرة عالية في تحسين خواص الترب الرملية وترشيد المياه بها.