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Gypsum Polymorphism in the Desert Environment of Abu Dhabi Emirate

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Abstract

Gypsum ($CaSO_4.2H_2O$) is a common mineral in semi-arid and arid environments. The quantity of gypsum and location in the soil profile determines soil taxonomic class. The gypsum mineral has several varieties that differ by shapes "*polymorphism*" of the crystal and their textural arrangements. These crystals have been of great interest due to their effect on soil properties. Gypseous soils have been the focus of many studies, but those studies mostly concentrate on their mapping, distribution and management. Very few studies have presented gypsum morphologies in arid environment. The present study aims at describing gypsum polymorphism in the desert environment of Abu Dhabi Emirate. Gypsum crystals were described in the field as they exist, and also hand specimen of gypsum crystals were collected and photographed. Gypsum soils found in the desert environment of Abu Dhabi Emirate were classified, according to the USDA Soil Taxonomy, under the following great group levels: Haplogypsids, Petrogypsids and Calcigypsids. The formation of gypsum in these soils could be attributed to geological or pedogenic processes. The geological gypsum occurs in many shapes; however, pedogenic gypsum does not retain the form of geologic gypsum in soil environment. The common morphological forms of gypsum found in Abu Dhabi Emirate are lenticular, euhedral, rosettes, fibrous, tubular, fan, massive, exfoliated, honey comb or porous, powdery, bottlebrush, and rock outcrop. These forms are developing different internal and external soil features. Each of these forms is fully described in this paper.

Keywords: Gypsum; polymorphism, Abu Dhabi; arid regions, rosettes; lenticular; fan; rock outcrop; bottle brush.

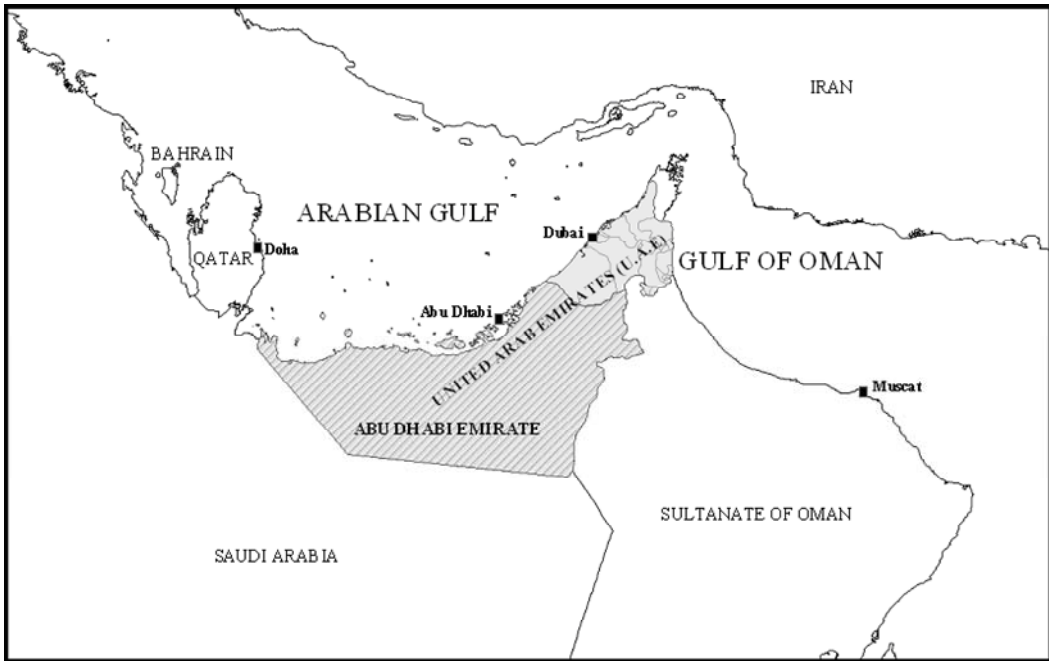
1. Introduction

The United Arab Emirates (UAE) is composed of seven Emirates, Abu Dhabi, Dubai, Sharjah, Ajman, Fujairah, Ras Al Khaima and Umm Al Quwain. Abu Dhabi Emirate is the largest among them with an

area of about 77,000 km^2 (Fig. 1). Abu Dhabi major ecosystems comprise the coast, numerous islands, mountainous areas, gravel plains and sand desert [1]. Nearly 80% area of Abu Dhabi Emirate is sandy desert, to the north and west is an extensive area of coastal flats locally known as "sabkha". The isolated sabkha surrounded by dune and gravel desert also exists which is called inland sabkha or interdunal sabkha. Abu Dhabi Emirate experiences extremely high temperatures during summers (45-50ºC) with mean temperature being 28ºC and short mild winters with temperature as low as 3oC [2]. Humidity is the highest along the coastal fringes and decreases inland. The mean annual rainfall is about 111 mm [3].

Gypsum ($CaSO_4.2H_2O$) is one of the most common building materials used in the world. It is used for interior walls, partitions and ceilings, either as plaster or in prefabricated products. Gypseous soils contain sufficient amounts of gypsum (calcium sulfate) to interfere with plant growth [4]. Gypsum rich soils are either of pedogenic or geogenic origin, the pedogenic gypsum found in regions with ustic, xeric and aridic moisture regimes. These soils are well represented in dry areas, such as the Arabian Peninsula, where sources for the calcium sulfate exist but do not usually occur under wet climates. In most cases the gypsum is associated with other salts of calcium and salts of sodium and magnesium [4].

Figure 1: Location of Abu Dhabi Emirate in the United Arab Emirates



Gypsum is a semi-soluble salt which is more soluble than calcite ($CaCO_3$) but much less soluble than other soluble salts like halite (NaCl) and thenardite (Na_2SO_4). Due to its solubility and contribution to electrolyte concentration, many scientists consider it as salt, others not as it does not increase osmotic potential or ion toxicity. The deserts of Abu Dhabi Emirate are rich in soil diversity, presenting soils rich in calcium carbonates and equivalents (Calcids), gypsum (Gypsids), soluble salts (Salids), loose sand (Psamments) as well as gravelly and hardpan soils [5 and 6]. When gypsic horizon starts within the 18 cm from soil surface, the soils are classified, according to the USDA Soil Taxonomy [14], as *Leptic Haplogypsids*, and within 18cm to 100 cm from surface, they are classified as *Typic Haplogypsids*, when gypsic horizon co-exists with calcic horizon they are classified as *Typic Calcigypsids*, and when cemented/solidified gypsum layer exist within upper 100cm, they are classified as Typic Petrogypsids.

Gypsum ($CaSO_4.2H_2O$) is often found naturally in semi-arid and arid soil environment. It is moderately soluble and readily precipitated. The presence or absence of gypsum in soil should be

considered when making management decisions in salt-affected soils. Due to its solubility, low cost, and availability, it is considered as the most commonly used amendment for reclaiming soil sodicity or through offsetting harmful affect of high-sodium irrigation water. The addition of gypsum increases soil permeability by increasing Ca concentration and reducing exchangeable sodium percentage in soil. Both gypsum and calcite ($CaCO_3$) are the precipitates commonly considered in salinity models.

Salt minerals morphologies in soil environment have been reported by many workers, for example halite (NaCl) morphologies [7,8] and thenardite (Na_2SO_4) morphologies [9]. In a recent study [10] various forms of soil gypsum have been described, this presents geological gypsum to occur in many crystalline forms, such as saccharoidal (alabaster), satin spar, rose and serenity. The saccharoidal, the most important commercially, resembles lump sugar and occurs as massive beds. Sartin spar is fibrous in appearance, has a satin luster, and firm thin discontinues layers. Rose gypsum grown in arid conditions, and serenity is transparent, often colorless, crystalline variety. This study [10] further describes the lenticular gypsum to be the most common pedogenic form, but other forms do occur. Other described tabular, prismatic, acicular, fibrous, granular and massive forms of gypsum [11].

Gypseous soils have been the focus of many studies, but those studies mostly concentrate on their mapping, distribution and management. Very few studies have presented gypsum morphologies in arid environment. In recent studies of Abu Dhabi coastal lands [12 and 13] thirteen different soil families have been reported using the USDA-NRCS system of Soil Taxonomy [14 and 15]. These studies focus mainly to soil characterization and mapping, however, they lack description of gypsum morphologies in the desert soil environment. Different morphologies develop different soil fabrics that control soil behavior to different uses, and therefore, form the focus of the present investigation.

2. Materials and Methods

During a recent soil inventory of Abu Dhabi Emirate [16], as a part of soil description a number of gypsum forms were observed and their quantities and distribution within soil profiles described using USDA field handbook [17]. The soil inventory covers the entire Abu Dhabi Emirate with a scale of 1:100,000 following the 4^{th} order level of the USDA Soil Taxonomy [14, 15, and 18]. The various forms of gypsum were either photographed in the field or hand specimens were collected, which were cleaned with brush and air blower, and photographed using digital camera. The morphologies of the different types of gypsum crystals identified in the desert environment of Abu Dhabi Emirate are fully described in this paper, the description is supported by digital photographs.

3. Results and Discussion

This is the first ever study in Abu Dhabi Emirate focusing on gypsum morphologies. Various morphological forms (polymorphism) as developed in the desert environment of Abu Dhabi Emirate are described in this paper.

3.1. Polymorphism of Gypsum

Gypseous soils are commonly found in Abu Dhabi Emirate desert environment. Gypsum occurs in different shapes and sizes on different landscapes, as exposed to surface due to wind erosion and in soil matrix. Most common forms are presented in this paper.

3.1.1. Lenticular Crystals

Pedogenic ***lenticular*** gypsum crystals were found in the costal lands of Abu Dhabi Emirate. These crystals were most common in *Gypsic Haplosalids* soils. The crystals were well developed lenticular plates, greenish and size ranges from 5 to 40 cm (diameter) and 2-5 cm thickness (Fig. 2). The crystals were embedded randomly in the soil profile. Lenticular form is typical of desert environment. The

small sized (upto 1 cm diameter) and 2-3 cm thick lenticular gypsum crystals covered upto 30-40 percent of soil surface. Lenticular or lens-shaped, when applied to minerals it refers to concretions or nodules that have a flattened, lens-like shape. The area where Gypsic Haplosalids soil was mapped in the coastal lands was devoid of vegetation due to very high soil salinity (hypersaline) and water table fluctuates within 100 to 200 cm from soil surface. The soil has continuous intrusion of sea water and subsequent evaporation have increased salts and the soil has lost its capacity for plant growth.

Figure 2: Pedogenic lenticular gypsum crystals as seen in the Gypsic Haplosalids soil in the coastal lands of Abu Dhabi Emirate

Lenticular gypsum in Gypsic Haplosalids

Lenticular gypsum crystals collected from profile

Gypsic Haplosalids soil is very strongly saline, ECe ranges between 239 dS/m (0-20cm) to 222 dS/m (120-140cm) [12]. Water table was observed at 140cm. Red color iron (Fe) mottling shows the effect of wetting and drying cycles (Fig. 2). Gray color shows reducing soil condition. The soil occurs on level landscape in the coastal lands and was barren and devoid of any vegetation.

3.1.2. Gypsum Fans

Gypsum fans are another interesting form of gypsum observed, it was exposed at soil surface due to deflation of soil material, indicating that sufficient soil has been removed through wind erosion. Such features show that the soil is exposed to extensive wind erosion. This is one of the indicators of land degradation in arid region soils due to aeolian mechanism. The fan crystals are white, 3-4cm wide and 30-40cm above the ground (Fig. 3). The material deposited around fan base is common under such condition, protecting the fan at base from further wind affect. The gypsum fan was recorded on the surfaces of *Gypsic Haplosalids* soils.

Figure 3: Gypsum fans exposed at surface of *Gypsic Haplosalids soils*

3.1.3. Massive and Exfoliated

Weathered gypsum through cleavage planes with the affect of both physical and chemical affects can expose internal surfaces (Fig. 4). The exfoliated gypsum presents internal structure for external affects leading to accelerated weathering. Field observation shows white gypsum of relatively much purer than the rock outcropped pinkish gypsum. Exfoliated gypsum commonly occurs at surface rather than deeper in soil profile. Massive is a term used to describe a rock or mineral that has no particular shape. Once the massive form is exposed to soil surface, the environmental affect can disaggregate or weather the surface of the massive form. The massive form is whitish and has more than 90% gypsum purity.

Figure 4: Massive and Exfoliated Gypsum

Weathered massive form of gypsum Weathered gypsum showing exfoliation

3.1.4. Gypsum Rock Outcrop (massive structure)

Gypsum was also found as a rock outcrop. The common color of the gypsum outcrop is light reddish. Commonly the surface is covered with eroded sand masking original structure (Fig. 5). Such deposits are an excellent source of gypsum material for commercial purposes. Common uses are in cement factories, construction (gypsum slabs) and use as amendment to reclaim soil sodicity to improve soil structure. These rock outcrops occur in the west of Abu Dhabi Emirate in Sila area.

Figure 5: Gypsum rock outcrop in the west of Abu Dhabi Emirate at Sila

Massive pinkish gypsum rock outcrop, sand cover due to erosion is also evident

3.1.5. Fibrous Gypsum

Fibrous gypsum is commonly found in desert environment (Fig. 6). This was found both in the coastal and inland desert soils. The fibers gypsum crystals were either parallel or randomly oriented. The fibers were exposed to surface due to loss of surface soil, due mainly to wind erosion; eroded sand was deposited in the crystals and in surrounding area. The fibrous gypsum is more than 95% pure with insignificant impurities. Fibrous or aggregate means the mineral is constructed of fine, usually parallel threads and some fibrous minerals contain cloth-like flexibility, meaning they can be bent around and feel like cotton.

Figure 6: White fibrous gypsum exposed at the surface

Fibrous gypsum in inland desert gypseous soil

3.1.6. Bottlebrush gypsum

Bottlebrush is a rare form in the arid and semi-arid region soils. In the present study it was found as crystallized gypsum over plant material forming into bottle brush (Fig. 7a). The initial development of bottlebrush over plant material with red color due to red algal growth is given below. This specimen was removed from hypersaline (EC >250 dS/m) basin where sea water was accumulated. The laboratory analyses show the water chemistry dominated with Na, Cl & SO_4. The precipitation of minerals from liquid phase is determined from their solubilities, the low solubility mineral precipitates first and the high the last. This is the reason that gypsum was crystallized over plant material. The Na and Cl remained in solution; further evaporation will crystallize halite (NaCl) from hypersaline solution. The dead plant was found in the basin, where gypsum was seeded. An advance stage of bottle brush is shown in Figure 7b. This was found in Al Sammalih Island of Abu Dhabi Emirate, where, the bottlebrush gypsum invaded existing native vegetation "*zygoplyllum qatarense*".

Figure 7: Bottlebrush gypsum found in the coastal lands of Abu Dhabi Emirate

a) Initial stage of bottle brush development

b) Well developed bottlebrush gypsum

3.1.7. Gypsum Roses

Gypsum roses are commonly found in arid and semi-arid environment. In the present study these were found in a *Gypsic Haplosalids* soil (salt rich soils). In this soil they were found in relatively pure form without evidence of sand inclusion (Fig. 8a). The soil was rich in soluble salts and developed over water table at 140 cm depth. Gypsum roses were randomly scattered in salty sandy soil material. The surfaces of crystals were shining and oriented to form a shape like desert rose. The rose petals size ranges from less than a cm to 5 cm diameter.

Rosette mineral with concentric aggregates resembling rose flowers (Fig. 8b) with significant sand inclusions were found in *Typic Petrogypsids* soils (gypsum hardpan soil). Both, relatively purer and with sand inclusions were observed at subsurface. The gypsum roses observed in inland (Fig. 8c) were in pinkish color and shows oxidation environment. The soils where pinkish roses were observed were rich in ferruginous sand, which have been included to roses crystals. These pinkish roses were relatively impure and contain red sand.

Figure 8: Desert gypsum roses found in desert environment of Abu Dhabi Emirate

a) Relatively pure gypsum roses found in salt rich soils (Gypsic Haplosalids)

b) Sand rose – aggregate of lenticular gypsum crystals with sand inclusion

c) Undisturbed pinkish (Fe rich) gypsum roses under field conditions

3.1.8. Tubular Gypsum

Tubular gypsum was another interesting feature found, these are elongated gypsum tubes (lenticular gypsum arranged to form elongated tubular form) with serrated surfaces (Fig. 9). Field observations revealed that the tubular form (rough surface non serrated) developed in channels of dead plant roots. The growing crystals at surfaces range from 5-15cm. Figure 9 presents a number of gypsum forms collected from desert environment of Abu Dhabi Emirate, rough surface tubular form is at the rear, along with serrated type on the front. The tubular form was observed on the surface of *Leptic*

Haplogypsids soils (the soil where gypsum rich layer was found within 18 cm from soil surface), developed in the interdunal area.

Figure 9: Rough surface tubular gypsum form along with serrated surface features

Rough surface tubular form (rear) along with serrated type elongated gypsum form (center)

3.1.9. Weathered lenticular gypsum crystals

The weathered lenticular gypsum crystals (2-3 cm long and 1 cm wide) randomly oriented were observed on the surface of a gypsic soil, forming a 5 cm surface capping on the soil (Fig. 10). The crystals were reddish in color due to Fe staining from ferruginous sand. The gypsum capping was underlain by calcareous sand and a 5cm gypsum hardpan at 30 cm depth.

Figure 10: Gypsum capping by disoriented gypsum crystals at soil surface

Soil capped by gypsum crust

Disoriented weathered gypsum crystals at soil surface

3.1.10. Euhedral Crystals (Sandy-Gypsic)

The well developed ***euhedral***, sandy-gypsum crystals were found at the surface of gypseous sandy soils (*Leptic Haplogypsids*). These crystals also include sand sized particles in their structure and therefore have impurities. The faces of the crystals are very sharp and well developed. Some of the

crystals are overgrown showing twining habits. The euhedral crystals are in different sizes ranging from 1 to 2 cm in length (Fig. 11).

Figure 11: Well developed euhedral, sharply edged sandy-gypsum crystals

3.1.11. Honey Comb Structure (Puffed Gypsum) and Powdery Gypsum

Porous (puffed) gypsum showing *honey comb* structure was oftenly found in subsurface petrogypsic horizon (solidified gypsic layer) (Fig. 12). Such form is highly prone to water entry into its structure, with high dissolution rates leading to high soil subsidence of landscape. Occurrence of such a layer under building foundations would be a threat to causing cracks and collapse of buildings through soil subsidence. Porous gypsum near irrigation water channels also cause collapse their structure causing floods. Exposures of this material to arid environmental conditions cause the surfaces of gypsum to look like powdery gypsum.

Figure 12: Powdery and honey comb “puffed” gypsum

Powdery gypsum at surface

Honey combed (puffed) type porous gypsum

4. Conclusions

Gypseous soils are common in the desert environment of Abu Dhabi Emirate, occurring both in the coastal land and inland. Worldwide gypseous soils have been focus of many studies, but mainly to their mapping, distribution and management. Very few studies have presented gypsum morphologies in arid

environment, and this is the first study in Abu Dhabi Emirate. From the present study it is concluded that in the arid environment of Abu Dhabi Emirate gypsum exists in many shapes “polymorphism”. Common gypsum morphologies found are fibrous, desert rosette, tubular, well developed euhedral sandy gypsum crystals, fan, lenticular, massive rock outcrop, honey comb or puffed, powdery, exfoliated and bottlebrush.

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