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Soil Distribution Pattern and Gypsic Soils of Alqatif Oasis, Saudi Arabia

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Abstract. Alqatif Oasis, on the Arabian Gulf, is the largest agricultural area in the eastern Saudi Arabia. Field studies indicated that this area was formed on a base of Tertiary Dam and Hardrukh marls, with low ridges representing older gulf levels. During the Quaternary period, sand dunes were deposited on the higher flats in the west, and evaporites formed playas or sabkhas on depressions between ridges of the flats. The dominant minerals in soils are calcite, aragonite, gypsum, orthoclase, and quartz. However, dolomite was the dominant carbonatic mineral in the soils on older geological formations.

Soils on sand dunes and flats are classified as siliceous, hyperthermic, Typic Torripsamments, and fine carbonatic, hyperthermic, Typic Calciorthids respectively. Due to the presence of a local aquic soil moisture regime, a hyperthermic soil temperature regime, and a gypsic horizon in younger sabkha soils, a new subgroup "Aquic Gypsiorthids" is introduced. It is suggested to add this subgroup to the Gypsiorthids great group of the Soil Taxonomy. Also a new method was introduced for the estimation of soil age.

Introduction

Alqatif Oasis, 7500 ha, is the largest cultivated area in the eastern coast of Saudi Arabia (Fig. 1). It extends along the Arabian Gulf between Ras Tannurah in the north and Al Dammam in the south. A natural barrier of Quaternary sand dunes accumulations separates the oasis from the hinterland in the west. Soils to the east are flats and sabkhas, dominated by marine sediments from Dam and Hadrukh marl and calcareous sandstone of Tertiary age [1]. The Pleistocene regression following the Upper Pliocene transgression of sea levels had their impact on Alqatif Oasis [2,3]. The soils of the Gulf coast area are dominated by aragonite, calcite, dolomite, gypsum, anhydrite, and halite [4]. Their proportion and distribution vary in different locations. According to Lee *et al.* [5], the clay fraction is dominantly smectite with lower amounts of mica, palygors kite and very small amounts of vermiculite, kaolinite, and occasional chlorite.

The mean annual soil temperature is 23.8°C, and the difference between mean summer and mean winter soil temperature is 11.2°C at 50 cm depth. The rainfall is

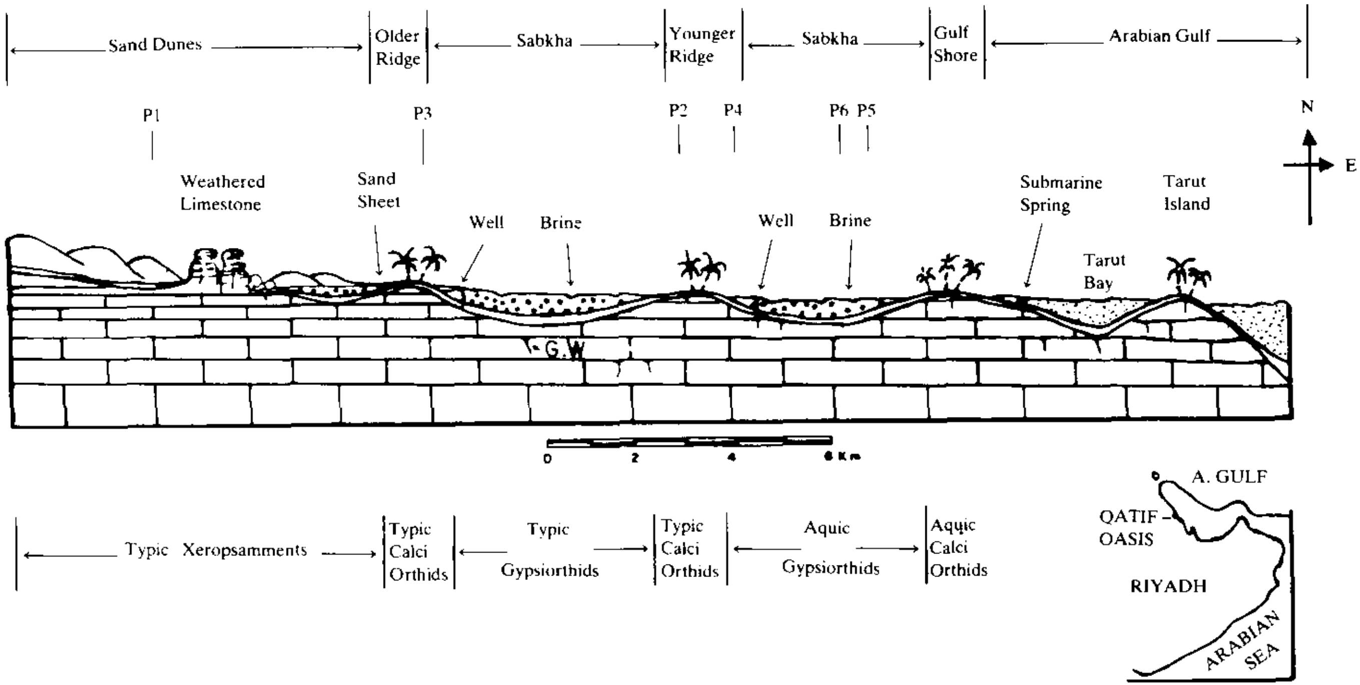

Fig. 1. Schematic diagram of the sequence of soils and major geomorphological features in Alqatif Oasis, S.A.

very irregular with an average of 63 mm/yr; the dry period exceeds six months [6]. According to Soil Survey Staff [7], the soils have hyperthermic temperature and generally aridic moisture regimes. However, an aquic moisture regime was observed in sabkha soils. In addition to the naturally flowing wells, hundreds of shallow wells are dug in palm gardens that are scattered in the whole oasis. Some submarine springs are also found in Tarut bay (Fig. 1). The aquifers of these naturally flowing wells are considered as one hydrological unit with a total discharge of 80.000 m^3/d [8]. Isotope studies indicated that salt water intrusion from the Gulf is excluded [9, p. 93,10, p. 153]. The aim of this work was to bring forward the presence of aquic soil moisture regime in some of the Gypsiorthids of Alqatif Oasis and to suggest a new subgroup for Gypsiorthids which is a great group recognized fairly recently, and was provided mainly for use in arid regions of the world.

Materials and Methods

Infrared aerial photographs with scale 1:20.000 were interpreted in order to study the genesis of Alqatif Oasis, and served as a base for field investigations. Descriptive terminology of representative soil profiles conforms with the nomenclature of Soil Survey Staff [7]. The methods of the U.S. Salinity Laboratory Staff [11], were applied for the analysis of soil and water samples, and the salt contents of the dominant natural vegetations in the area. Sodium tripolyphosphate was used as a dispersing agent for particle size analysis without removal of carbonates. A soil column, 8 mm in diameter, was used for the capillary potential measurement of water. X-ray analysis was done on oriented powdered soil particles < 2 mm. A Phillips diffractometer with Ni filtered Cu K_α radiation was used to measure basal spacings.

Results and Discussion

Distribution pattern of soils in relation to the landscape and the geology of Alqatif Oasis is shown in Fig. 1. Three main soil associations were identified:

Sand dune soils

This association consists of complex and barchan mobile quartz sand dunes of the Quaternary [1]. They extend almost parallel to the Arabian Gulf shore on the western fringe of the Oasis (Fig. 1). Their height ranges up to 25 m (Profile 1, Table 1).

Marine terraces association

This represents soils formed on tidal flats of the Lower Miocene, Dam and Hadrukh marl and calcareous sandstone. The ridges of the flats may represent older gulf levels. This association is subdivided into older terraces in the west (Profile 3, Table 1), and younger terraces to the east (Profile 2, Table 1). They are covered with sand sheets and scattered low sand dunes (Fig. 1). The soils of the terraces are highly calcareous, saline, sandy clay loam to clay, with calcic horizons that are more developed in older terraces; the water saturation conditions impede horizon differentiation in younger teraces.

Table 1. Some physical and chemical characteristics of soil profiles studied

Prof. no.	Horizon	Depth cm	Particle size distribution, mm Clay 0.002	Silt 0.002-0.05	Sand 0.05-2	Texture	$dS\,m^{-1}$	pH_s^*	Calcium carbonate equiv.	Gypsum	OM.
			%						gkg^{-1}		
1	AC	0- 25	4.4	9.2	86.4	S	1.90	8.0	12	9	1.8
	C1	25- 70	3.7	11.1	85.2	S	1.75	8.1	15	12	1.2
	C2	70-100	7.2	9.3	83.5	LS	1.65	7.9	17	12	1.2
	C3	100-160	7.9	9.1	83.0	LS	1.72	7.9	19	10	0.9
2	AP	0- 10	22.1	10.4	67.5	SCL	35.75	8.4	720	9	31.6
	C1k	10- 35	17.4	18.5	74.1	SL	32.33	8.1	790	9	6.0
	C2	35- 70	30.2	4.6	65.2	SCL	42.65	8.2	660	11	5.8
	C3	70-110	27.3	7.7	65.0	SCL	48.66	8.4	484	13	6.6
	C4	110-170	29.7	8.1	62.2	SCL	46.35	8.3	488	11	4.8
3	AC	0- 40	54.6	19.3	26.1	C	11.54	8.0	460	28	11.0
	C1k	40-120	57.1	36.4	6.5	C	2.46	8.3	680	20	10.3
	C2	120-200	80.3	14.4	5.3	C	3.41	8.1	440	20	10.3
4	Ap	0- 30	13.5	6.5	80.0	SL	11.54	8.0	210	130	29.0
	Cy1	30- 65	19.2	8.4	73.4	SL	12.57	7.9	160	650	1.0
	Cy2	65-110	11.1	13.7	75.2	SL	10.43	8.1	100	264	8.0
	C1	110-160	12.4	11.5	76.1	SL	5.20	8.3	120	110	5.0
5	Ap	0- 3	9.4	19.3	75.3	SL	57.40	7.8	50	310	18.7
	Cy1	3- 25	7.2	28.5	67.3	SL	45.65	8.2	56	510	11.6
	Cy2	25- 60	9.4	30.4	60.2	SL	38.42	8.2	26	620	13.2
	Cz	60- 90	9.3	28.1	62.6	SL	101.50	7.5	116	640	16.8
	C1	90-144	10.6	19.4	70.0	SL	69.73	7.5	160	330	15.4
6	Ap	0- 15	15.2	16.4	68.4	SL	91.50	7.3	42	380	18.2
	Cy1	15- 40	18.4	15.1	66.5	SL	84.90	7.3	26	820	9.5
	Cy2	40- 70	18.9	15.1	63.8	SL	59.30	7.5	24	765	8.1
	Cz	70-115	23.8	25.0	51.2	L	138.20	7.3	85	183	6.2
	C1	115-135	17.3	19.1	63.6	SL	86.70	7.4	146	95	6.2
	C2	135-170	17.1	18.4	64.5	SL	38.20	7.3	353	91	4.4

* pH_s : pH of the saturated paste.

Sabkha soil association

This represents gypsiferous highly saline sandy loam soils of the coastal and inland playas (Profiles 4,5, and 6 respectively). They are separated from the main mass of the Gulf water by a shallow shelf, The sabkhas are mainly evaporites of gypsum formed in depressions between ridges of the terraces. Some sinkholes and scattered low gypsum dunes are observed in inland playas, while brines are scattered in coastal playas (Fig. 1).

The Dam and Hadrukh formations were identified in depressions between sand dunes, in ridges of the terraces, and at varying depths in sabkhas. Accordingly, it is concluded that the soils of Alqatif Oasis are formed on a base of these Tertiary formations.

Sand dunes are aeolian deposits of the Quaternary. Soils on sand dunes were classified as siliceous, hyperthermic Typic Torripsamments. Soils of the terraces are on marly formations of marine origin. Less leaching in older terraces caused the development of shallow calcic horizons (Profile 3, Table 1). As seen from the 0.288 nm peaks (Fig. 2), dolomite is the dominant mineral in the whole soil (particles < 2 mm in diameter), and it increases with depth. Due to the hyperthermic soil temperature, and the generally aridic soil moisture regime, and the presence of calcic horizons, these soils were classified as fine carbonatic, hyperthermic, Typic Calciorthids.

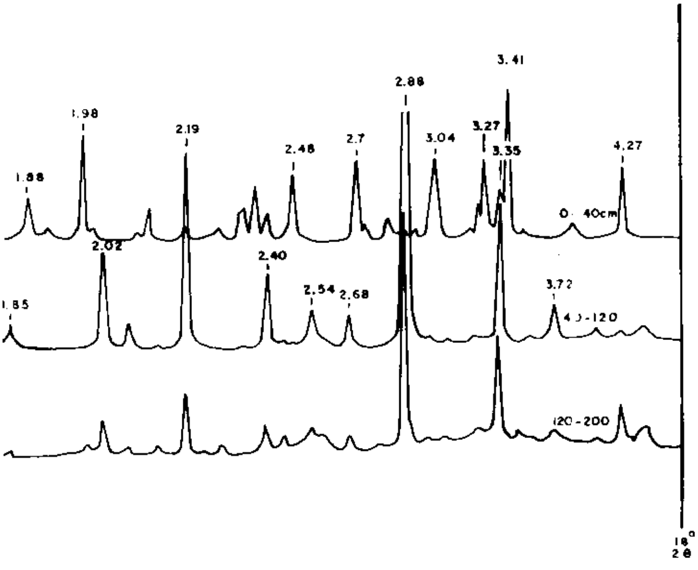

Fig. 2. X-Ray diffraction of oriented < 2 mm soil fractions for Al-Qatif, profile no. 3

The dominant minerals in the soils of the younger terraces are calcite, aragonite, and quartz (0.303, 0.340, and 0.334 nm respectively, Fig. 3). Dolomite is very low in these formations [12, p. 267]. Due to the continuous supply of fresh water from the scattered naturally flowing wells, most of which is infiltrated and the ground water was seldom allowed to concentrate with salts. This induced permanent water table causes a local aquic soil moisture regime. Accordingly, younger terraces are classified as loamy, carbonatic, hyperthermic, Aquic Calciorthids.

The sabkha soil association (Profiles 4,5, and 6, Table 1), is characterized by a gypsic horizon which is confirmed by the 0.287, 0.426, and 0.756 nm diffraction peaks (Fig. 4). It is formed as powdery evaporites on the surface and accumulated on plant remains. It is considered that the brines are in equilibrium with their environment; evapotranspiration concentrates the brine leading to the precipitation of Ca in soil or its accumulation in the plants. Climate was assumed to be similar over the last 10.000 yr. Accordingly, the amount of gypsum added to the soil from irrigation and ground water is calculated as follows:

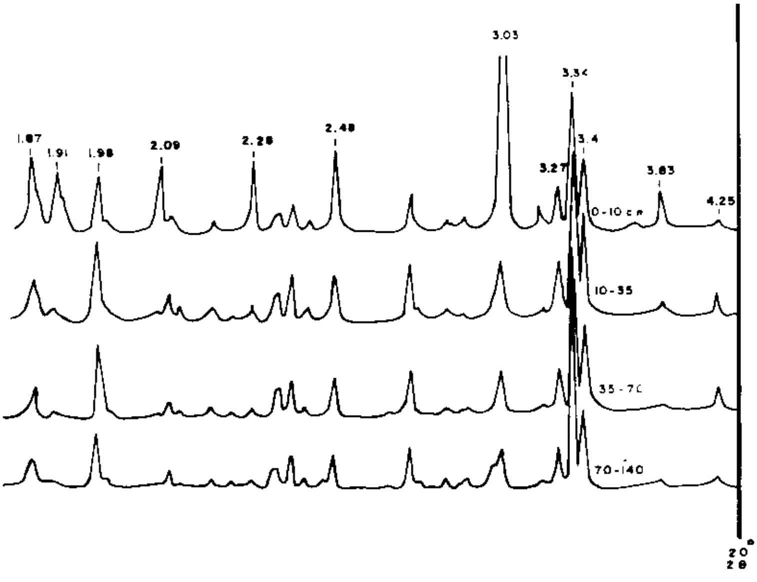

Fig. 3. X-Ray diffraction of oriented < 2 mm soil fractions for Al-Qatif, profile no. 2

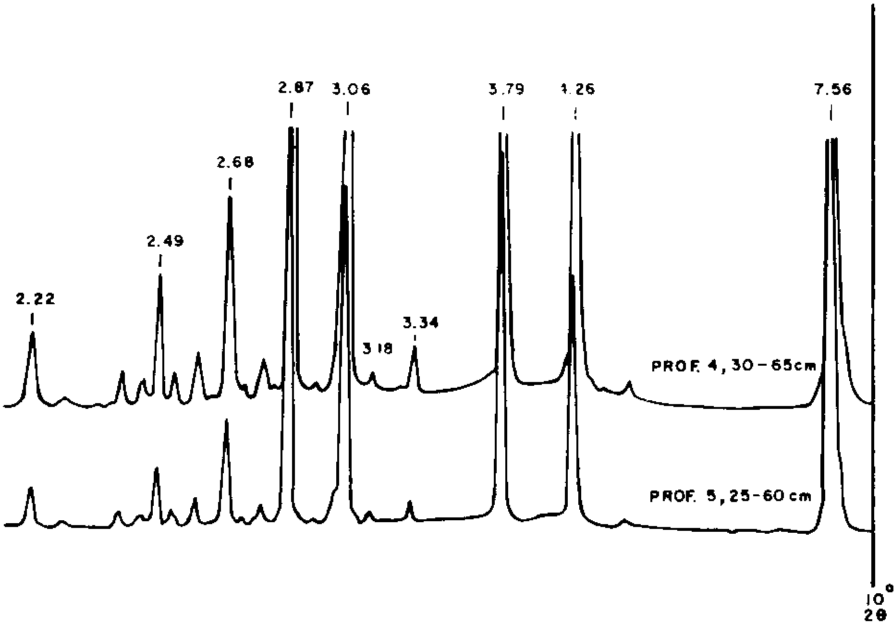

Fig. 4. X-Ray diffraction of oriented < 2 mm soil fractions for Al-Qatif

Evapotranspiration (Italconsult, [6])	11800000 m^3/yr
Ca concentration in water (determined)	192 g/m^3
Average Ca utilized by crops (Doll and Lucas, [13, p. 133])	85 kg/ha
Bulk density of gypsic layers (determined)	1.46 Mg/m^3
Area of the oasis	7500 ha
Total Ca in water	2265600 kg/yr
Total Ca in crop residue	637500 kg/yr
Ca precipitated in soil	1628100 kg/yr
Gypsum added to the soil	7000830 kg/yr
Thickness of gypsum added	$\frac{700083 \times 1000}{7500 \times 10^8 \times 1.46} = 0.0064$ cm/yr

Assuming that the average depth of the gypsic layer in sabkha is 120 cm, and its gypsum content is 50 %, accordingly, the age of the sabkha is

$$\frac{120}{0.0064} \times \frac{50}{100} = 9375 \text{ yr.}$$

The effect of the biological factor in the authigenic formation of the gypsic horizon was studied (Table 2). It was found that plant remains serve as subsurface wick for evaporite formations. Gypsification takes places in stems and rhizomes of dead plants. The presence of bands of gypsified plants representing successive vegetative cycles, indicates that gypsum is of a diagenetic origin (Fig. 5). Gypsum is concentrated from ground water in these remains and around the ends of grazed stems forming hummocks or low dunes of sand-like gypsum particles coated with decomposed organic materials.

Table 2. Salt contents of dominant plant species in Alqatif oasis

Plant	Percent in dry matter					
	Live plant			Dead plant remains		
	$CaSO_4$	$CaCO_3$	NaCl	$CaSO_4$	$CaCO_3$	NaCl
Spirogera sp. (in drains)	0.50	0.00	2.00	25	0.3	12.0
Juncus maritimus	0.60	0.22	4.20	75	1.2	8.0
Phragmites communis	0.45	0.25	2.60	82	2.4	9.6
Inula crithmaides	0.32	0.46	0.85	88	0.7	6.3

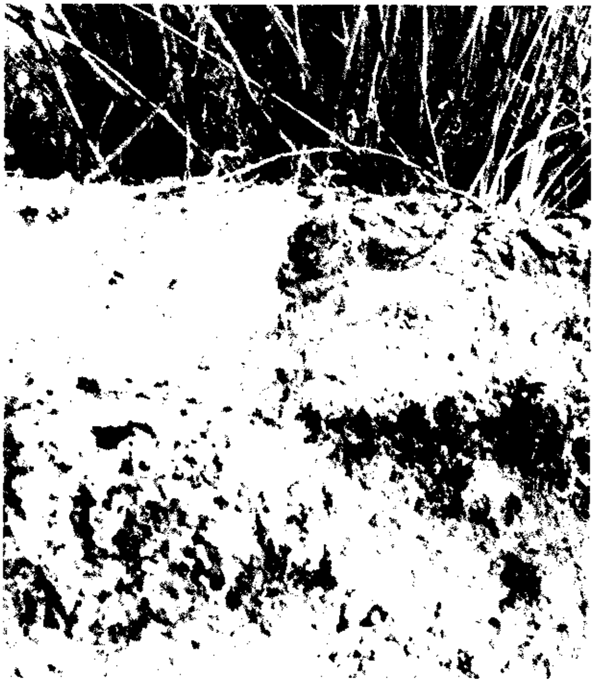

Fig. 5. Gypsified rhizomes of *Inula crithmaides*, Alqatif Oasis, Saudi Arabia.

Carbonates seem to concentrate within and below the gypsic horizon in Profile 5. This indicates that gypsum and calcium carbonate deposits are formed by capillary rise in the Sabkha soils. Measurement of the capillary rise in columns of the gypsic layers gave an equilibrated value of 142 cm after 18 h.

Soils of inland sabkhas were classified as loamy, gypsic, hyperthermic, Typic Gypsiorthids. However, it was not possible for the soils of coastal sabkha to be classified at the subgroup level with the present criteria. Due to the prevalence of a local aquic soil moisture regime, a hyperthermic soil temperature regime, a gypsic horizon and mostly a salic horizon in coastal sabkha soils, a new subgroup "Aquic Gypsiorthids" is suggested. This subgroup could possibly be added to the Gypsiorthids great group of Soil Taxonomy [7]. Salic horizons develop mostly in soils far from springs or naturally flowing wells where no leaching takes place. Evapotranspiration rate is 1850 mm/yr, compared to an annual rainfall of 63 mm/yr [6]. The author found widespread areas of this subgroup in coastal soils of Egypt and Libya in addition to Saudi Arabia.

Soils in the "Aquic Gypsiorthids" subgroup differ from Typic Gypsiorthids in that they are permitted but are not required to have more organic matter. They are saturated with water for 90 consecutive days or longer in most years in the gypsic horizon and/or some subhorizons that are shallower than 1 m. In addition, these soils undergo a very limited leaching compared to a very high evaporation or evapotranspiration rate.

Classification: Aquic Gypsiorthids.
Location: Alqatif Oasis, 25 km to the west of the Arabian Gulf; Profile no. 5.
Physiographic position: Coastal playa (sabkha), with scattered gypsum dunes and few brines, elevation 1 to 2 m asl.
Topography: Almost flat, with gradient less than 5%.
Drainage: Poorly drained.
Vegetation: Sparse cover of annual weeds.
Parent material: Evaporites of gypsum.
Sampled by: Ahmed Youssef, Nov. 1982.

0-3 : Ap — Pale brown (10 YR 5/3); sandy loam; very pale brown (10 YR 7/3), when dry; very fine granular; very friable; abrupt smooth boundary.

3-25 Gy1 — Pale brown (10 YR 6/3); sandy loam; very pale brown (10 YR 7/3), when dry; fine granular; friable, slightly sticky, slightly plastic; common fine pores, bands of rhizomes; gypsiferous; diffuse smooth boundary.

25-60: Cy2 — Light yellowish brown (10 YR 6/4); sandy loam; very pale brown (10 YR 7/4), when dry; weak, medium subangular blocky breaks to fine granular; common fine and few coarse roots and rhizomes; few fine pores; dark gray cleavage planes (10 YR 4/1), and reduction bands of Fe^{2+} (red on ignition); gypsiferous; clear smooth boundary.

60-90 Cz — Light yellowish brown (10 YR 6/4); sandy loam; very pale brown (10 YR 7/4), when dry; moderate, medium subangular blocky; common fine and few coarse roots; bands of gyosified rhizomes; common medium pores; dark gray cleavage planes and bands (10 YR 4/2); gypsiferous; clear smooth boundary.

90-144: C1 — Pale brown (10 YR 6/3); sandy loam; very pale brown (10 YR 7/3), when dry; blocky, breaks to weak subangular blocky; sticky, plastic; thin reduction bands of Fe^{2+} (10 YR 4/1).

Classification: Aquic Gypsiorthids.
Location: Alajam, 8 km north of Alqatif; Profile no. 6.
Physiographic position: Coastal playa, with sand-like gypsum dunes and few brines, elevation 2-5 m asl.
Topography: Almost flat, with gradient less than 5%.
Drainage: Poorly drained with water table at 80 cm depth.
Vegetation: Palm trees and sparse cover of annual weeds.
Parent material: Evaporites of gypsum.
Sampled by: Ahmed Youssef, Feb. 1984.

0-15 : Grayish brown (10 YR 5/2); sandy loam;

Ap	brownish gray (10 YR 6/2), when dry; very weak granular; very friable; slightly sticky, slightly plastic; few fine roots; few discontinuous vesicular pores; clear wavy boundary.
15-40 Cy1	Yellowish brown (10 YR 5/4); sandy loam; white (10 YR 8/2), when dry; weak massive breaks to weak fine subangular blocky; sticky, plastic; few fine and medium roots; few vesicular pores; gypsiferous; diffuse wavey boundary.
40-70: Cy2	Yellowish brown (10 YR 5/4); sandy loam; white (10 YR 8/2), when dry; weak fine subangular blocky; slightly sticky, slightly plastic; friable; few medium roots; gypsiferous; clear smooth boundary.
70-115: Cz	Yellowish brown (10 YR 5/6); loam; very pale brown (10 YR 8/3), when dry; massive breaks to weak angular blocky; sticky, plastic; few fine white concretions and gypsum crystals; clear smooth boundary.
115-135: C1	Brownish yellow (10 YR 6/6); sandy loam;yellow (10 YR 7/6), when dry; massive breaks to weak fine angular blocky; sticky, plastic, with dark gray interceptal stripes (5 YR 4/1); few fine concretions and shell fragments; calcareous; clear smooth boundary.
135-170: C2	Brownish yellow (10 YR 6/6); sandy loam; yellow (10 YR 7/6), when dry; massive breaks to angular blocky; very sticky, very plastic, with dark gray interceptal stripes (5 YR 4/1); few shell fragments; calcareous.

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الأراضي الجبسية بواحة القطيف، المملكة العربية السعودية

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ملخص البحث. تقع واحة القطيف على الخليج العربي وتعتبر أكبر المناطق الزراعية بالمنطقة الشرقية بالمملكة العربية السعودية. وقد أظهرت الدراسات البيدولوجية أن هذه الأراضي تكونت على قاعدة من الحجر الجيري تكوين الدمام - حدروكا من العصر الثلاثي يتخللها بعض الحواف البارزة والتي تمثل مستويات مختلفة لسطح الخليج في الأزمنة السابقة. وقد ترسبت الكثبان الرملية في العصر الرباعي على الشرفات المرتفعة في الغرب، وانحصرت الأحواض التبخرية والبلايا والسبخات في المنخفضات بين الحواف المرتفعة. وقد أظهرت النتائج سيادة معادن الكالسيت، الأراجونيت، الجبس، الأرثوكلاز، والكوارتز مع كميات قليلة من معادن الطين. ولم تسمح الظروف بعد بتكوين الدولوميت بالترسيبات الحديثة.

وقد قسمت أراضي الكثبان الرملية ضمن: Siliceous, Hyperthermic, Typic Torripsamments والأراضي المرتفعة ضمن: Carbonatic, Hyperthermic, Typic Calciothids.

ونظرًا لسيادة مناخ رطوبي محلي مائي ومناخ حراري حار مع وجود أفق جبسي بأراضي السبخات فقد اقترح المؤلف إدخال تحت مجموعة جديدة Aquic Gypsiorthids لتسكين هذه الأراضي.