Pedological study of Omayed toposequence northwestern mediterranean desert of Egypt

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ABSTRACT

Twenty one profiles representing a 10 km toposequence in Omayed area were described and sampled for this study. Results of total calcium carbonate, total soluble salts, organic matter and particles size distribution were represented diagrammatically in horizontal and vertical sequence along the North South transect. The main characteristics distinguishing the soils in the lower part were the solum thickness, presence or absence of subsurface diagnostic horizons, and the natural vegetation cover. The soil on the upper end of the transect was identified as a Lithic Torripsamment (sol salsodique salin sur sable au-dessus de roche dure) *and the soil on the lower end appeared as a* Typic Torripsamment (sol peu évolué gris subdésertique). *The intermediate profiles were noted to have characteristics of* Aridisols *(mostly* calciorthids*) due to the actual arid climate. A few are* salorthids ; *others are salt affected. The genesis of these soils appears to be controlled mostly by their geomorphic surface, the age and the nature of their parent material. Two of the major pedological processes expressed in that sequence are migration and accumulation of calcium carbonate, mostly on old and subactual deposits, and salinization mostly on the most recent ones.*

KEY WORDS : Egypt — Aridisols — Toposequence : salted, subdesertic, calcimagnesic soils — Calcium carbonate accumulation — Salinization.

RÉSUMÉ

ETUDE PÉDOLOGIQUE DE LA TOPOSÉQUENCE D'OMAYED DANS LE DÉSERT SUR LA CÔTE MÉDITERRANÉENNE N.O. DE L'EGYPTE

Vingt profils de sols, correspondant à une toposéquence de 10 km, du nord au sud depuis la Méditerranée, ont été étudiés et échantillonnés. Les résultats analytiques rapportés concernent leur constitution granulométrique, leur teneur en calcaire total en matière organique et en sels solubles. Ils sont représentés sur des graphiques en fonction de leur répartition verticale et latérale. Les caractéristiques principales des sols de la partie basse, septentrionale, de la toposéquence sont la profondeur du solum, la présence ou l'absence d'horizons diagnostiques et le type de la couverture végétale naturelle. Les sols de la partie haute, méridionale, sont classés comme Torripsamments Lithiques (Sols calcimagnésiques sablo-caillouteux à croûte calcaire) *et ceux de la partie basse le sont comme* Torripsamments Typiques (Sols peu évolués subdésertiques sur sables). *Les sols des profils intermédiaires présentent tous des caractéristiques d'*Aridisols *(Sols peu évolués ou sols isohumiques ou calcimagnésiques xériques ou salsodiques) dus au climat aride. La formation de ces sols paraît dépendre surtout de l'âge du dépôt sur lequel ils ont pris naissance et de la surface géomorphologique correspondante, ainsi que de la nature du matériau originel. Deux des principaux processus pédologiques exprimés dans les sols de cette séquence sont la migration et l'accumulation du calcaire, surtout sur les matériaux anciens et sub-récents, et la salinisation, principalement sur les matériaux les plus récents.*

MOTS-CLÉS : Egypte — Aridisols — Toposéquence : sols salés, subdésertiques, calcimagnésiques — Accumulation calcaire — Salinisation.

INTRODUCTION

In the light of the growing interest in the development of desert areas of Egypt with the view of increasing the national income, and releasing the high pressure of the population on cultivated land in the Nile Delta and Nile Valley, a great effort has been devoted to the proper management of the northwestern mediterranean coastal region of Egypt. It has the relatively most favourable climatic conditions, and the best land potentialities of all Egyptian deserts. The present study has been carried out within the framework of the project on « Regional Environmental Management of Mediterranean Desert Ecosystems of Northern Egypt » (REMDENE-MAB Program), which has been initiated with the ultimate goal of providing a basis for land management recommendations towards the better utilization and conservation of natural resources and the enhancement of their sustained productivity. The objective of this work is to characterize the morphological features, the physical an chemical properties of the soils of Omayed toposequence and classify them in definite units and relate them to their possible utilization.

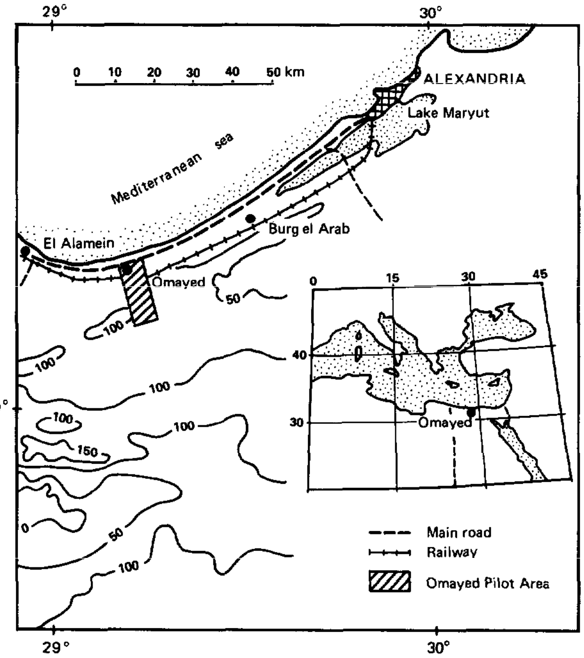

FIG. 1. — Location map. *Schéma de localisation*

THE STUDIED AREA

Omayed area, chosen for this study, is a part of the northwestern mediterranean coastal zone of Egypt. It is located at about 80 km West Alexandria. The approximate geographic coordinates are 30° 45' to 30° 50' north latitude, and 29° 10' to 29° 15' west longitude. It is bounded by the Alexandria-Salum coastal road on the north, by the arbitrarily chosen lines on the East and West, and by the 100 m contour of Kashm El-Aish on the South (fig. 1). It extends along the coastal road for about 5 km, with an average inland depth of about 10 km.

Based on the bioclimatic map of the Mediterranean zone, it has a subdesertic warm climate, UNESCO/FAO (1963). It is characterized by one rainy season. The collected climatic data (1) from 1957 to 1960 show that most of the rainfalls during the period between October and February, with an annual average precipitation of 168 mm/year with a maximum of 41.4 mm in one day (February), at the coastal zone, which decreases rapidly southward. However, the amounts of the rainfall varied considerably around this average from one year to the other. The monthly mean temperature varies between 15 °C in January and 26 °C in August. The mean relative humidity is 68,9 % with a maximum of 83 % in June. Variations in wind velocity are less distinct than those of other climatic features ; The Winds are mostly either from the North-West side or from the North-East one, depending upon the time of the year ; It is noted that autumn months are distinguished by low wind averages when compared with other months.

Geological studies on the northwestern mediterranean coast of Egypt suggest that formations in the area under consideration are essentially of quaternary and tertiary ages (SAID, 1962). The geological map prepared by SHATA (1957) indicated that the surface deposits are of Pleistocene time, while the subsurface formations are of Miocene time.

Geomorphologically speaking, the area under study may be distinguished into three sectors. The southern sector is constituted by the Libyan Plateau of which the hard calcareous sandstone is, by places, covered by a thin layer of sandy or loamy deposits. The northern, foreshore sector is characterised by a typical topographic configuration. This is a serie of elongated calcareous ridges of more or less recent marine origin alternating with sandy depressions all oriented in a north-east, south-west direction. The intermediate sector is an ondulated plain structured by order ridges due to a strong quaternary faulting of the northern border of the Libyan Plateau. Its altitude increases from the coastal sector to the foot of the plateau. It is formed by deposits of mixed aeolian and colluvial origin. The

(1) At Dekheila — 65 km East of Omayed.

formation of a calcareous crust has developed throughout a great part of the quaternary times ; thick and very hard (slab) over the old limestone, it strongly decreases over the more recent formations (indurated oolitic dunes).

MATERIALS AND METHODS

Prior to the field study, the interpretation of the aerial photographs (1 : 25000) was done. The results were compiled on a photo-mosaic of 1 : 25000 scale. Twenty one profiles were dug along a north-south transect (fig. 2), in order to represent the different soil units. Profile descriptions were carried out according to the terminology cited by the Soil Survey Staff (1975). The soils were sampled by horizons and auger samples were taken below the pit dug to the bed rock or to a depth of 150 cm. Soil samples were analysed using the methods outlined by RICHARDS (1954) and BLACK (1965).

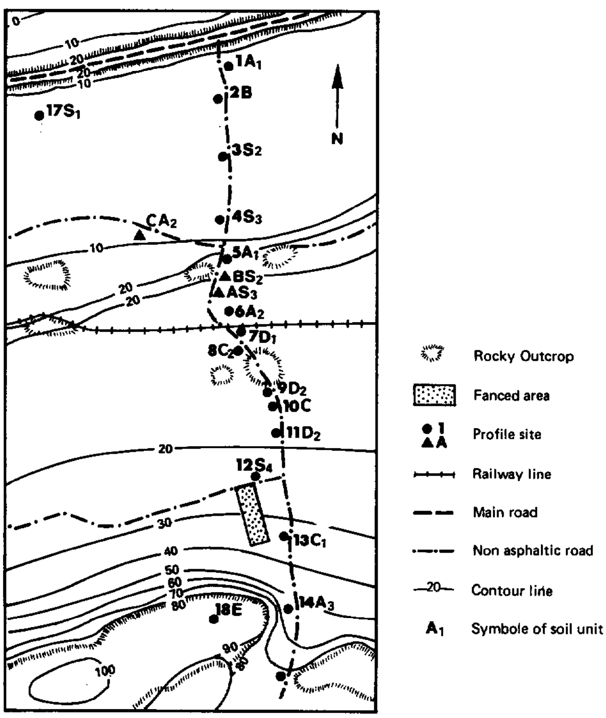

FIG. 2. — Omayed Pilot area. *Secteur pilote d'Omayed*

Soils were classified through both USDA soil taxonomy (Soil Survey Staff, 1975) and French Classification (Commission de Pédologie et de Cartographie des Sols, 1967).

RESULTS AND DISCUSSION

1. Mapping units

Six mapping units were recognized. The following are the description of each unit based on the macromorphological features, physical and chemical properties of representative soil profiles.

A — UNIT

This unit includes the sandy soils of the recent coastal plain and of the piedmont of the plateau. They are light in color, low in organic matter, deep, non-saline, calcareous without or with zone of slightly defined lime accumulation. The unit mostly developed in the lower end of the toposequence. It had a very low salt content increasing with depth where EC values between 0.4 and 1.6 mmhos/cm. It was divided into three subunits.
A_1 — subunit : Flat land ; Contains a slight friable lime accumulation at the surface (profiles 1 and 5).
A_2 — subunit : Flat land ; Has developed from a mixed eolian-colluvial sand over consolidated oolitic sand (profile 6) ; normally deep to very deep. By places it may contain spots of soils of smaller depth.
A_3 — subunit : Has a slightly slopy topography (glacis) with 2-3 % slope (profile 14) ; deep to very deep.

A_1 — *subunit*

The following is the macromorphological description of the representative soil profile n° 1, which is a very typical one :

Location : Omayed, about 400 m south of the main Alexandria-Matrouth road.

Physiographic position : Near to south of the foot of the second ridge.

Elevation : About 10 m over the sea level.

Topography : Almost flat.

Drainage : Well drained.

Land occupation : Ficus carica and *Citrulus vulgaris.*

Parent material : Wind-blown and alluvial sand.

Description : On the surface many particles of shells :

0- 33 cm Very pale brown (10 YR 7/4) fine sand ; single grained, loose (dry) with 3-4 cm crust at the surface ; cavernous porosity ; few fine fresh roots ; many small shell fragments ; gradual smooth boundary.

33- 82 cm Yellow (10 YR 7/6) fine sand ; weak subangular blocky ; friable (moist) ; few fine and coarse fresh roots ; some scattered shell fragments ; diffuse smooth boundary.

82-145 cm Yellow (10 YR 8/6) fine sand ; weak subangular blocky ; firm (moist) ; no roots, some scattered shell fragments.

145 cm + A clayey sand layer of stressed marine shells, slightly saline.

Note : All the samples were non-sticky, non plastic (moist) and had a violent effervescence with diluted HCl.

CLASSIFICATION

Typic Torripsamment (sol peu évolué gris subdésertique éolisé sur sable calcaire d'apport d'origine mixte, au-dessus de sable argileux marin coquillier, de zone plane interdunaire, très profond).

In the soils of the A_1-subunit, $CaCO_3$ content is high and normally constant with depth, with only a small accumulation at the surface and decreases in the second horizon. Profile n° 1 is typical for that with 34,3 % from 0-33 cm, then 32,5-36-35,7 and 32,1 % at 160-210 cm (tabl. I). In some soils the variation is slighty stronger as in profile n° 5 where $CaCO_3$ is 33,4 at the surface, then 26,8 and 37,5 % at 86-150 cm. The texture is fine sand at the surface horizons, changes into sandy clay with depth as in profile n° 1 and to medium sand and then to coarse sand as in profile n° 5.

Under dry farming practice (rained agriculture), these soils are used for fig and almonds trees as they are growing successfully with very little management. The soils of the A-unit are usually very useful, but they have low water holding capacity and are somewhat deficient in plant nutrients. The best suggested economical use for such soils is to put under drip irrigation, where water is available, in order to produce a good agricultural rating of fruit trees and fodder crops or improved pastures. The supply of fertilizers, specially nitrogen, will be, in most cases, necessary.

TABLE I

Total carbonates percent, electrical conductivity of the saturated extract (m.mhos/cm), and organic matter percent

Unit or Subunit	Profile	Depth cm	$CaCO_3$ %	E.C. m.mhos/cm	O.M. %
A_1	1	0–33	34.3	0.5	0.00
		33–82	32.5	0.6	0.03
		82–145	36.0	0.7	0.35
		145–160	35.7	1.0	0.04
		160–210	32.1	1.3	0.16
B	2	0–30	26.4	5.0	0.73
		30–47	21.8	2.9	0.39
		47–67	12.5	4.9	0.25
		67–93	27.9	7.0	0.22
		93–155	–	9.0	0.30
		155–195	–	11.0	0.30
C_1	13	0–46	25.0	0.5	0.44
		46–107	45.7	1.2	0.32
		107–200	31.1	4.6	0.35
C_2	8	0–30	20.5	1.8	0.26
		30–56	25.0	7.0	0.41
		56–78	49.1	12.5	0.29
		78–107	57.3	15.0	0.15
		107–125	39.6	9.0	0.20
D_1	7	0–43	63.6	1.1	0.46
		43–63	50.0	4.4	0.29
		63–125	71.4	5.5	0.17
E	18	0–30	22.1	6.5	n.d.
S_1	17	0–16	32.1	90.0	n.d.
		16–35	33.8	80.0	n.d.
		35–75	46.5	40.0	n.d.
		75–95	28.2	38.0	n.d.
		95–110	26.6	42.0	n.d.
		110–130	19.5	32.0	n.d.
S_2	3	0–15	36.8	23.0	0.00
		15–33	26.1	24.0	0.57
		33–54	26.8	50.0	0.21
		54–77	52.7	37.0	0.55
		77–140	96.4	26.0	0.32

B — UNIT

The soils of this unit are moderately deep, saline, calcareous with a significant zone of gypsum accumulation defined as a gypsic horizon. The most common natural vegetation is *Limoniastrum monopetalum* and

Zygophyllum album. The following is the macromorphological description of the representative soil profile n° 2 :

Location : Omayed, about 800 m south of the main Alexandria-Matrouh road.

Physiographic position : Depression between 2nd and 3rd ridges.

Elevation : About 10 m.

Topography : Flat.

Drainage : Rather well drained.

Parent material : Wind blown sand and deposited marine origin sand over lacustrine saline clay.

0- 30 cm : Light yellowish brown (10 YR 6/4) fine sand ; massive to slightly coarse columnar ; very compact (dry) ; non-sticky, non-plastic (moist) ; violent effervescence ; some old root channels ; fine and medium pores ; clear smooth boundary.

30- 45 cm : Yellowish brown (10 YR 5/8) fine sand (moist) ; coarse medium subangular blocky ; firm (moist), non-sticky, non-plastic ; violent effervescence ; few fine pores ; some fine roots ; scattered shell fragments ; clear smooth boundary.

45- 55 cm : Very pale brown (10 YR 7/4) fine sand (moist) ; weak fine subangular blocky ; friable (moist) ; non-sticky, non-plastic (moist) ; violent effervescence, few fine pores ; shell fragments ; few scattered white spots (lime) ; faint mottles ; very few fine roots, smooth boundary.

55- 67 cm : The same, but more clayey with more white spots (lime and gypsum), abrupt boundary.

67- 93 cm : Dark grayish brown (2.5 YR 4/2) moist clay ; fine and medium subangular blocky ; violent effervescence ; firm (moist) ; sticky, plastic (moist) ; many patches of gypsum powder, some crystals in packets ; few iron stains, mottles ; abrupt smooth boundary.

93-155 cm : light brownish gray (2.5 YR 6/2) clay (moist) ; medium and coarse subangular blocky ; slightly firm, slightly plastic (moist) ; violent effervescence ; numerous fine to coarse gypsum crystals ; many iron stains.

CLASSIFICATION

Calcic Gypsiorthid (Sol peu évolué subdésertique faiblement salé à faciès hydromorphe, éolisé sur sable et limon argileux au-dessus d'argile lacustre, moyennement profond).

B-unit covers the smallest area of the studied sector. Carbonates content is moderate to high. It varied between 12,5 to 27,9 % showing an accumulation at the surface horizon (26.4 %) and at 67-93 cm (27.9 %). The texture class is variable with depth from medium sand to very coarse sand then to clay, respectively. The unit B has a moderate to high salt content (E.C. between 2.9 in the sub-surface horizon and 11.0 mmhos/cm in depth). It increases gradually with depth, but sometimes shows a slight accumulation at the surface (E.C. 5.0 mmhos/cm). The soils of this unit may be utilised as a dry pasture or for cultures under irrigation and drainage.

C — UNIT

Soils of this unit are very deep calcareous sand (100 cm depth) over soft to hard calcic horizon. It is divided into two subunits according to their salinity level.

C_1 — subunit : is on gentle slope and not salt affected, (profile n° 13).
C_2 — is level and salt affected, (profile n° 8).

C_1 — subunit

The following is the macromorphological description of the representative soil profile n° 13.

Location : Omayed, about 8000 m south of the main Alexandria-Matrouh road.

Physiographic position : On the northern slope of the plateau.

Elevation : About 35 m over the sea level.

Topography : Slightly undulated.

Drainage : Well drained.

Land occupation : Many desert shrubs dominated by *Thymelea hirsuta* and *Echiochilon fructicosum.*

Parent material : Wind blown and colluvial fine silty sand.

0- 46 cm : Light yellowish brown (10 YR 6/4) fine sand ; weak, slightly granular ; friable ; few fine and medium pores ; some fine and coarse fresh roots ; few small shell fragments ; abrupt smooth boundary.

46-107 cm : Very pale brown (10 YR 7/4) (dry) ; fine sand ; massive ; compact ; some medium pores ; few hard and some soft lime concretions ; few fine roots ; gradual smooth boundary.

107-200 cm : Yellow (10 YR 7/6) (moist) ; fine sand ; massive ; firm ; few small hard lime concrestions.

Note : All the samples were non-sticky ; non-plastic (wet), with a strong effervescence using a diluted HC1.

CLASSIFICATION

Typic Calciorthid, (sol calcimagnésique carbonaté xérique à nodules calcaires, à faciès éolisé sur sable calcaire, en zone plane faiblement ondulée, très profond). Carbonates content is high (between 25.0 and 45.7 p. cent) with an accumulation of 45.7 % at 46-107 cm. The texture varies gradually from fine to coarse sand by depth. It has a low content of soluble salts ; E.C. values varies between 0.5 to 4.6 with descendent salt pattern (Table I).

The soils of this subunit are useful as a pasture under dry conditions using the run-off water. It may also be used for fruit trees under drip irrigation, where water is available.

C2 — subunit

In this subunit (profile n° 8), the soil profile is very similar with calcareous nodules from 56 to 78 cm and calcareous patches below, but it is salt affected mostly from 56 to 107 cm.

It is a *typic calciorthid* (sol calcimagnésique carbonaté xérique à nodules calcaires à facies salé et éolisé, sur sable calcaire moyen, entre rides calcaires, profond).

It mostly differs from the, previous one by its higher salt content in depth.

The soils of this subunit may be utilised as a dry pasture or under irrigation with an effective drainage system.

D — UNIT

The soils of this unit consist of a moderately deep consolidated sand with a hard formation of $CaCO_3$ as incrustation below a variable thickness of drift sand. They are moderately salt-affected. This unit was divided into two subunits :

D_1 — *subunit*

Has a very thin layer of drift sand (10-20 cm) by places over the surface of the indurated calcareous layer (profile 7).

D_2 — *subunit*

Was a thick layer of drift sand (50-60 cm), where the surface is undulated (profile 11).

The following is the macromorphological description of the representative soil profile n° 7 (D_1).

Location : Omayed, 4200 m south of the main Alexandria-Matrouh road.

Physiographic position : Platform over the distorted third ridge.

Elevation : 20 m.

Topography : Flat.

Drainage : Well drained.

Land occupation : Thymelea hirsuta vegetation.

Parent material : Wind blown-sand.

Profile 7

0- 5 cm : aeolian sand, abrupt boundary.

5- 15 cm : very pale brown fine sand, some fine calcareous segregations in patches (amas).

15- 25 cm : The same, with hard lime concretions, sometimes elongated.

25- 43 cm : more massive but with some pores, some lime concretions.

43- 60 cm : pale brown fine sand ; coarse subangular blocky ; many very hard big lime concretions in a very calcareous material (incrustation).

60- 70 cm : very pale brown (10 YR 7.5/4) fine sand ; coarse subangular blocky ; cemented ; many fine pores, few fine fresh roots ; small marine shell fragments, lime nodules and some scattered hard lime patches ; some imbedded fragmented sandstone, abrupt smooth boundary.

70-125 cm : White to very pale brown (10 YR 8/2) sand ; massive, cemented ; very compact ; few fine pores ; very few fine roots ; many shell fragments of various dimensions.

125 et + : White very calcareous material with marine shells.

Note : All the samples are non-sticky, non plastic (moist) ; and has a violent effervescence with HC1.

CLASSIFICATION

Typic Paleorthid, (sol calcimagnésique carbonaté xérique à encroûtement calcaire, faciès salé, sur sable calcaire et calcaire marin, en zone plane faiblement déprimée entre rides de calcaire induré et calcaire dur ou induré, moyennement profond).

The soils has a very high content of total carbonates. It is 63.6, 50.0 and 71.4 % respectively with depth. The soil texture is medium sand throughout the profile. Salt contents are moderate ; E.C. values were 1.1, 4.4 and 5.5 mmhos/cm respectively with depth (Table 1). The soils of this subunit are essentially useful for pasture because of the shallowness and the salt contents without easy drainage.

E — UNIT

Soils of this unit are very shallow, more or less saline, over calcareous massive crusting (incrustation) ; characterized by fairly continuous structure (non platy type) of the material over an « encroûtement », and compact slab in which the $CaCO_3$ content is between 70-90 % with salmon pink colour (platy type « dalle compacte » RUELLAN A. (1971)).

The following is the macromorphological description of the representative soil profile n° 18.

Location : Omayed, about 9000 m south of the main Alexandria-Matrouh road.

Physiographic position : The top of the rocky high land of the plateau.

Elevation : About 90 m over the sea level.

Topography : Almost flat.

Drainage : Well drained.

Parent material : Limestone.

The surface is gravelly to stony, originated from the eroded slab and crust.

0-30 cm : yellow (10 YR 7/6) ; silty sand gravelly (desintegrated slab and crust) ; moderate medium subangular blocky.

30-40 cm : Calcareous slab more or less brocken over a hard lim bed rock.

CLASSIFICATION

Typic Paleorthid, (Sol calcimagnésique carbonaté xérique à croûte calcaire sur grès calcaire dur, de plateau ou sur rides, très peu profond).

Total carbonates content in the fine soil is 22.1 %. It is 32 % in the coarser fraction (> 2 mm). That unit has a slight salt content (E.C. = 6.5 mmhos/cm) (Table I). It may be considered only as poor pasture.

S — UNIT

Soils of this unit are saline ; they are variable in their salinity, thickness and physiographic position. They are formed from calcareous sand over clayey sand or silty clay. This unit is divided into four subunits :

S_1 — subunit : has a very high salt content with an ascending salt profile and a thin salt crust on the surface. A new formation of gypsum in defined crystals may occured (profile n° 17).

S_2 — subunit : has a high salt content with an intermediate salt profile (profile n° 3).

S_3 — subunit : has a moderate salt content with a descending salt profile (profiles n° 4 and A).

S_4 — subunit : has a moderate salt content with a descending salt profile and a hard lime segregation (profile n° 12).

S_1 — subunit

The following is the macromorphological description of the representative soil (profile n° 17) :

Location : Omayed, about 1500 m west of the Omayed road and 800 m south of the main Alexandria-Matrouh road.

Physiographic position : Local plane depression south of the southern foot slope of the first rocky ridge.

Topography : Flat with low hummocky surface.

Drainage : Very bad.

Land occupation : Halocnemum strobilaceum, over the hummocks.

Parent material : Wind-blown sand and clayey sand.

On the surface, with salty efflorescences, thin salt hard and bloated pellicule ; by places, around the « nebkhas », pseudosand is creeping.

0- 16 cm : Yellow (10 YR 7/6) fine sand ; massive compact ; saline pseudo-mycelium ; thin crust of gypsum and sodic salt crystals on the surface ; some medium roots ; abrupt boundary.

16- 35 cm : (7,5 YR 7/6) yellow ; medium sand ; massive, compact ; some fine gypsum crystals ; fine hard lime concretions ; very few medium roots ; clear boundary.

35- 75 cm : (7,5 YR 7/6) yellow ; coarse quartz and calcareous oolitic sand ; massive, friable ; few pores ; diffuse boundary.

75- 95 cm : (10 YR 6/4) light yellowish brown ; clay sand ; massive ; moderately sticky, plastic (wet) ; clear boundary.

95-110 cm : (10 YR 7/4) very pale brown ; silty clay ; slightly developed subangular blocky ; few pores ; sticky, plastic (wet) ; water table at 100 cm.

110-130 cm : (10 YR 7/3 very pale brown moderate gray to reddish brown mottles clay ; sticky, plastic (wet).

CLASSIFICATION

Typic Salorthid, (Sol Salsodique très salé à alcali, surface friable à efflorescences, à pseudo-sable, facies hydromorphe gypseux à faible profondeur, très profond).

This profile has a high content of soluble salts with an ascending salt profile. E.C. values are 90, 80, 40, 38, 42, 32 mmhos/cm respectively with depth. $CaCO_3$ % is also high, decreasing with depth, and, probably, accumulates at 35-75 cm without appearing in « amas » ; it was 32.1, 33.8, 46.5, 28.2, 26.6 and 19.5 % respectively with depth (Table I).

This unit is not suitable for agriculture. Its improvment by submersion, drainage and Calcium enrichment would be too difficult and costly.

S_2 — *subunit*

The following is the macromorphological description of the representative soil profile n° 3 :

Location : Omayed about 1500 m south of the main Alexandria-Matrouh road.

Physiographic position : Depression between 2nd and 3rd ridges.

Elevation : About 10 m.

Topography : Flat with low to moderate hummocky surface.

Drainage : Well drained.

Land occupation : Dense *Limoniastrum monopetalum* covering the sandy hummocks.

Parent material : Wind blown sand.

0- 15 cm : Very pale brown (10 YR 7/4) ; fine sand ; weak fine medium subangular blocky ; firm ; non-sticky ; non-plastic (wet) violent effervescence ; few fine pores ; numerous fine fresh roots ; gradual smooth boundary.

15- 33 cm : Light yellowish brown (10 YR 6/4), (moist), sand ; massive ; friable ; non-sticky, non-plastic (moist) ; violent effervescence ; many fine roots ; clear smooth boundary.

33- 54 cm : Light yellowish brown (10 YR 6/4), (moist) sand ; weak fine subangular blocky ; friable ; non-sticky ; non plastic ; violent effervescence ; some fine roots ; few old root channels ; abrupt smooth boundary.

54- 77 cm : Light yellowish brown (10 YR 6/4), (moist), sand ; weak fine and medium subangular blocky ; slightly firm ; non-plastic (moist) ; violent effervescence ; many shell fragments ; many lime segregations ; few imbedded fragmented sandstone ; abrupt boundary.

77-140 cm : Very pale brown (10 YR 7/4), (moist), sand ; massive ; firm ; non-sticky, non-plastic ; violent effervescence ; no roots ; gradual smooth boundary.

140-165 cm : Very pale brown (10 YR 8/4), (moist), sand ; massive ; very compact ; non-sticky ; non-plastic ; some fine and coarse pores ; some shell fragments.

CLASSIFICATION

Typic Calciorthid, (Sol salin à surface friable, à profil salin intermédiaire éolisé sur sable limoneux et sable oolithique d'apport, en zone plane, très profond).

This soil has a high content of soluble salts ; E.C. is variable. These values vary between 23 and 50 mmhos/cm with an accumulation (50 mmhos/cm) at 33-54 cm. $CaCO_3$ % is varying between 26.1 and 96.4 %. It increases with depth with also a noticeable accumulation at the surface (36.8 %) (Table I). The texture is medium sand at the surface and become coarser in depth (Fig. 2a).

The soils of this sub-unit needs a very high quantity of water for leaching salts and they are very difficult and expensive to drain because of the undulated topography.

There are, also, by patches, soils very similar to salorthids, in places where the soil is thin to very thin.

2. Toposéquence relationships

The horizontal and the vertical repartition of the grain size distribution, the total soluble salts and the total calcium carbonate along the Omayed toposequence are represented in Figure 3.

2.1. THE GRAIN SIZE DISTRIBUTION

The texture is mainly sandy. It becomes coarser by depth, except in the first depression which, in the northern half, is clayey at the subsolum (Fig. 3c). Only in a small part of that depression soil is a little more silty and the less than 0,2 mm particle can attain 50 % of the material.

The origin of this material is complex. In the first depression it mostly derives either from lacustrine or lagoon deposits or from colluvial elements due to the weathering of the two colitic lime ridges, and also from aeolian sand. In some cases (profile 2) these various origins deposits are superposed by more or less thick layers. In most cases these originally different particles are mixed in the same layers (profiles 3 and 4). In the slight second depression and on the plateau and its southern side, in most cases the material is constitued by a mixture of particles derived from the underlying layer (specially on the plateau) and of aeolian sand, sometimes reworked by runoff.

The statistical analysis of the grain size distribution, following Griffith's method (1967) (Fig. 4) indicated that in most of the profiles, the mean (MD ∅) in the fine sand is ranged from 3.1 to 2.6. It is from 2.6 to 2.3 in the medium sand and from 2.3 to 0.9 in the coarse sand samples. The percental deviation (PD ∅) is between 0.4 to 1.6. It represents a highly sorted aeolian deposited material, transported by saltation. In some others (profiles 6 (70-96 cm), 8 (56-78 cm), A (40-75 cm), the sorting was not high, meaning the mixing of other, water transported, material.

2.2. THE TOTAL SOLUBLE SALTS

The salinity status reflects the various roles of parent material, climate, time and topography as the main factors affecting salt accumulation in the area (Fig. 3b).

The saline clay of the first depression (B-unit) is considered as a lagoon deposit. These clayey layers are covered by a weathered oolitic material derived from the two side ridges, then mixed and filled by a non salty wind blown material, so deep in some places (profile 1 and 5) that the soil itself is not salty (A_1-subunit). That zone might be the natural extension of the Maryût lake — BALL (1939). In Burg El Arab area ISMAIL (1971) found that the clay type of that depression

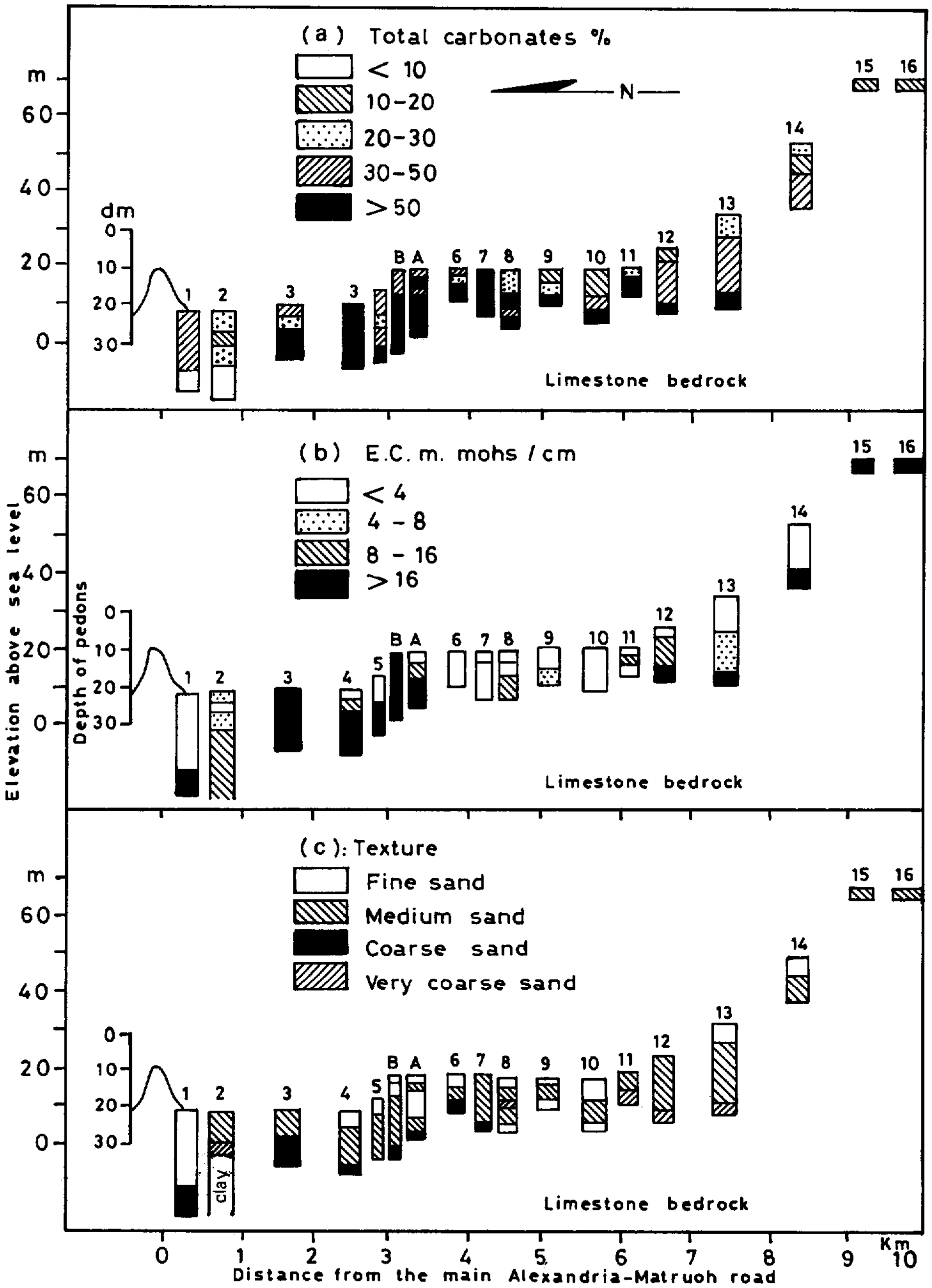

FIG. 3. — Distribution of total carbonates (a), soluble salts (b), texture (c), as a function of the topography. *Répartition des teneurs en carbonates totaux, en sels solubles, et en sables, en fonction de la topographie*

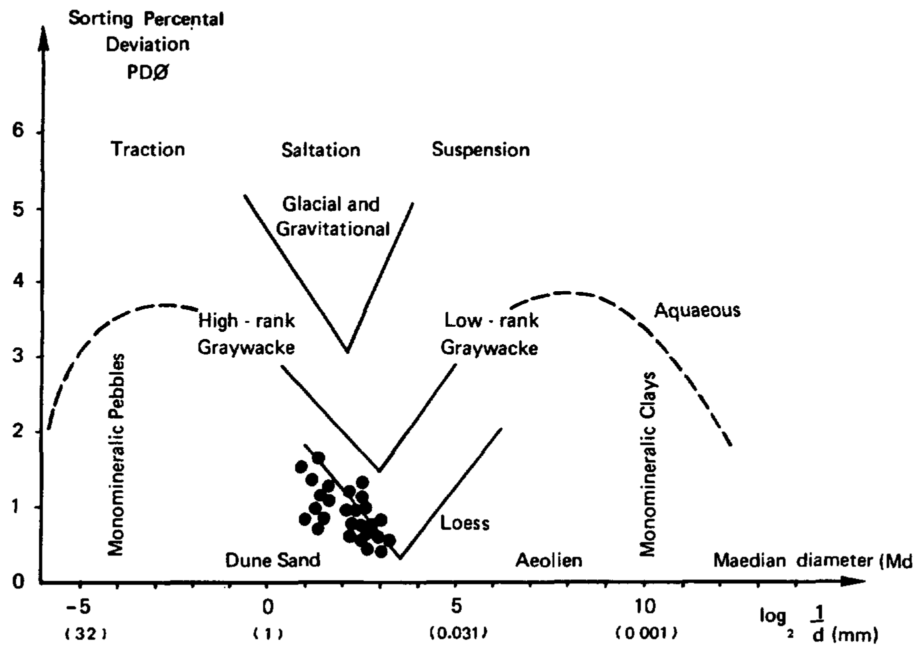

FIG. 4. — Size Md Ø (= P50) and size sorting PDØ $\frac{(= P75 - P25)}{2}$ plotted on the detrital sediments (GRIFFITH'S method, 1967) for the studied samples. *Diamètre moyen des particules (P = 50) et écart semi-interquartile de leur distribution* $\frac{(P75 - P25)}{2}$ *dans les échantillons étudiés (méthode* GRIFFITH, *1967)*

is related to lake Maryût. At the foot slopes of the first as well as of the second rocky ridges, the soils were, probably, originally saline ; then they were well leached (E.C. < 4 mmhos/cm). In these soils, salts are accumulated in relatively deep horizons (E.C. 8-30 mmhos/cm). That is due to the sufficient accumulated surface run-off water from the impermeable steep surface of the ridge and to the low capillary rise in that sandy soil materials (A_1 — subunit). At the middle part, the only fresh water resource is rainfall, which is not enough to remove down the soluble salts (B, S_2 and S_3 sub-units).

The second depression is different in salinity status, mostly due to the time factor and the slope patterns (A_2, C_1, C_2 and D_2 sub-units). Comparing the soil ages between the first and second depressions, the second one, which is older, received a total rainfall more than the first one ; so the surface horizon of the whole slight second depression is almost free from salts (E.C. < 4 mmhos/cm) as in profiles 6, 7, 8, 9, 10 and 11. The northern slope of the high land platform is relatively gentle (about 2 ‰). It consists of a deep permeable loose sand ; so a great part of the runoff water percolates the profile. The soluble salts are moved vertically, then laterally when reaching the limestone bedrock. They are accumulated at the foot slope (E.C. 4-16 mmhos/cm) as in profiles 11 and 12 (D_2 and S_4 sub-units).

At the last high land platform, the soils are saline by patches due to the proximity of the sea, and the wind action, to the weakness of actual rainfall and also to their shallowness.

Outside of the described transect, salt-affected soils are largely extended in the depression between the two oolitic ridges (S_1 — S_2 — S_3). We, previously, explained their origin and their actual evolution, for profiles

2 - 3 - 4 of the transect. Salts appear also sometimes in shallow soils, in connexion with rocky outcrops, as in E unit, by bare patches among other non saline soils, covered by vegetation, as it was found in the arid steppe zone of Southern Algeria by POUGET (1980).

As to the type of salt accumulation, Figure 5 shows the distribution of cations and anions of the saturated extract of the representative salty profiles. In the first depression (B-unit - profile 2), the salt type is mainly Na and SO_4 with a small of Mg, Ca and Cl which increases relatively in deep salty layer. Southward, Cl increases relatively and reaches about 3/4 of SO_4 in profiles 3 (S_2) and 4 (S_3), then about 1/1 in profile B and it was 5/1 of SO_4 in profile A. Mg increases also in the last one. The high content of SO_4 and Ca is related to the gypsum formed in lacustrine medium. In the second, older, depression, Na and SO_4 are mainly dominant (profiles 8 (C_2) and 11 (D_2). The high quantities of Cl of the southern soils are probably due to the salt accumulation by the northern wind, charged by the salty water from the sea. This wind could be stopped by the southern high altitude land as we already previously suggested.

It may also be thought that, even if not exactly in the same subunit, profiles A and B are correlated and have the same origin but that B, just at the border

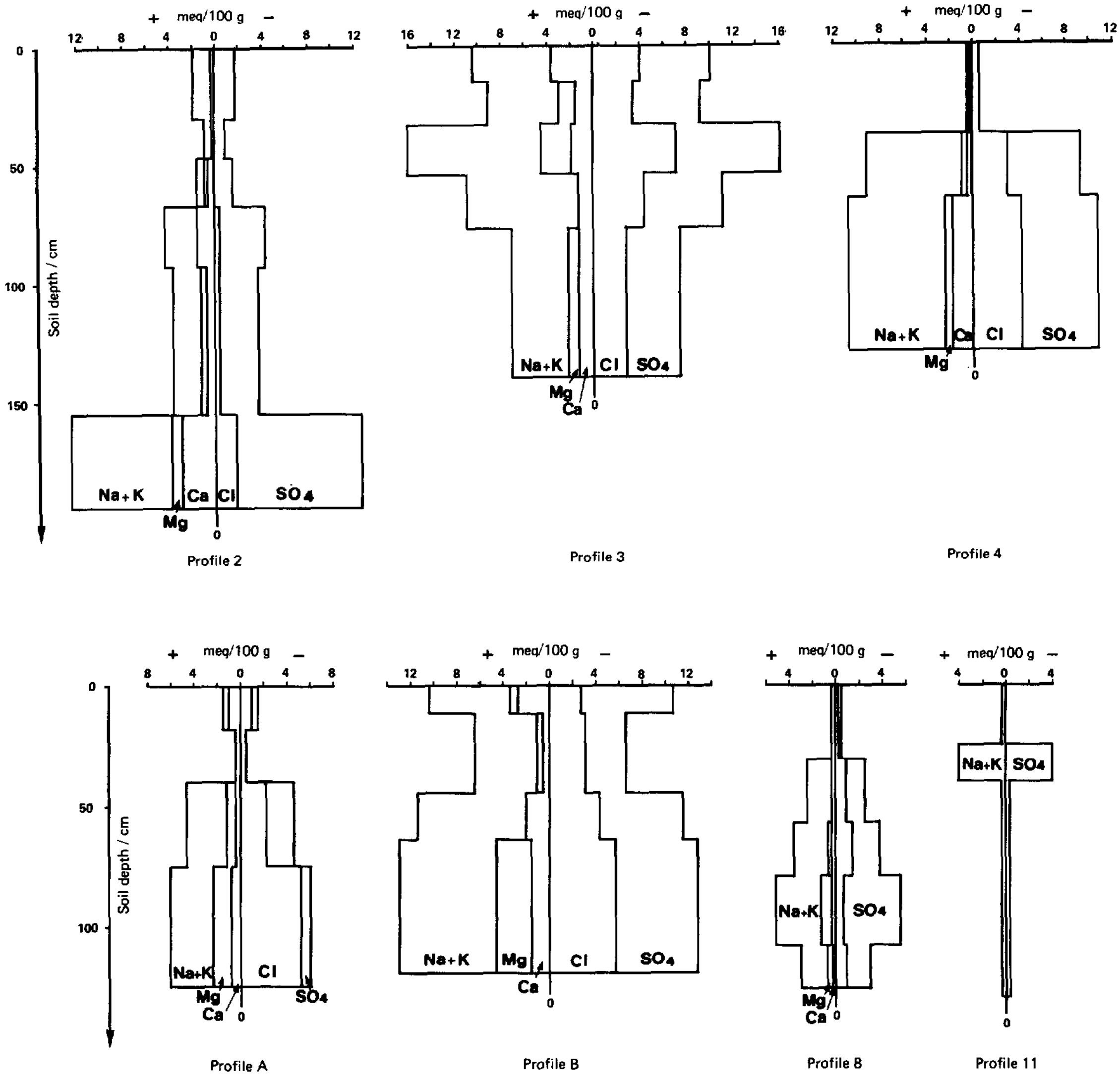

FIG. 5. — Distribution of cations and anions in the saturated paste extract, by depth. *Répartition des cations et anions de l'extrait de pâte saturé, en fonction de la profondeur*

of the small escarpment, has been more leached than A. That will explain its lower salt content at the surface and its lower Cl/SO_4 ratio because Cl is more easily washed than SO_4.

2.3. THE SPATIAL DISTRIBUTION OF THE TOTAL CALCIUM CARBONATE CONTENT OF THE SOIL (fig. 3a)

(a) This distribution is highly variable and, most often, its origin is complex. The calcium carbonate content of the various materials which contribute to the formation of all these soil materials is very heterogenous. Some of them are aeolian or colluvial sands coming from the oolitic beach sand, or from the elements due to the weathering of the oolitic ridges and are, highly or even excessively, calcareous, often more than 60 p. cent. Others are colluvial or sortly transported sands, of which the elements derive from the evolution of the different oolitic or sandstone ridges and plateau. They normally are very calcareous (20-40 p. cent). The last ones correspond to wind blown transported particles from the extended surface of the inland plateau. They are only slightly calcareous (less than 20 p. cent).
(b) The mixture and evolution of these elements started many thousands of years ago in some of the places and more recently in others. It goes on now. The stage which has been attained is not the same, in every place, because, mostly, the effect of age and of the various climatic conditions these formations had to support. It does not seem likely that hard and strong nodules which are part of deep horizon of soils in some of subunits of C and D units, or the calcareous slab which overlies the hard calcareous sandtone of the inland plateau (unit E) could be entirely due to actual processes. Their formation started during more rainy periods of the Quaternary age, but nothing proves that their evolution, by aggradation, degradation, or slightly progressive deepening down is not going on some more now a days. Observations made by EL ZAHABY at Burg el Arab (1970) or by us in some irrigated fields of the same sector are a strong basis for such an hypothesis.

The extension of irrigated sector in that zone and, later on in El Omayed, will increase the actual process of lime migration in the soils.
(c) The consideration of these, previously indicated, three origins of these soil materials and of their relative age, can help to explain the actual geographical distribution of the total lime content in the soils of the sector.
— In the depression between the two first rocky oolitic ridges, the total calcium carbonate content of the soils is high, (26,4 — 40,5 % CO_3Ca) because of the great importance of the oolitic sand in the composition of the parent material and because of the recent age of these materials and of these soils. In their deep horizons only slight accumulation of lime, in the form of friable « amas », can be observed. In southward part of the depression soils are richer than in the northern one, and in the deepest horizons than in the surface ones.
— In the flat non saline plain or slight second depression between the recent ridges and the inland plateau, the distribution picture is quite different. The surface first or two first horizons are not very rich (less than 30 p. cent), with a few exceptions where the lime content can exceed 60 p. cent, for some geomorphological reason. The lowest layers are much riche, with hard (sometimes big) nodules and lime incrustation (Unit C and D). This type of distribution seems to be due to long time active lixiviation of Ca CO_3 in the upper part of the soil and accumulation in the B Ca horizons. It also seems probable that some water table effect played a role in this picture. The total calcium carbonate content obtained from the analytical data often exceeds, in that case, 50 and even 60 p. cent in these deepest horizons.
— On the inland plateau, where, from every evidence, or strong indication, soils are much older, their surface horizons have a mean or low content of calcium carbonate in their fine earth (10 to 20 p. cent), but their coarse material and gravels, of which the content is very high, are almost entirely composed of limestone bits.
(d) If the soils of the depression between the oolitic rocky ridges are relatively recent, those from the non saline slight depression or relatively high plain and mostly from the inland plateau are much older ; they are not fossil but ancient soils.

That seems to allow us to interprate, through the age of the soils, the types of their lime accumulation :
— patches and mass in the most recent ones (depression between oolitic rocky ridges),
— nodules, often very numerous and big, or incrustation, in the middle zone plain, probably depending of other factors : type of permability, effect of water, table... ; the soils, there, are not so recent,
— calcareous crust and slab in the inland plateau oldest soils.

CONCLUSION

Soils of the investigated toposequence were found to be highly affected by the geomorphological factors and recent tectonic movements.

They (a) Soils developed on the recent marine plain : *Typic Torripsamments* (profile n° 1) ; (b) soils developed on the Maryut lake extension : *Typic Gypsiorthids* (profile n° 2) and *Salorthids* (profile n° 17) ; (c) soils developed on the limestone escarpment and out crops :

Typic calciothids (profile n° 3), *Typic Torripsamments* (profile n° 15), *Typic Paleorthids* (profile n° 7).

Soil genesis appears to be controlled, in the local climatic conditions, mostly by the age of the geomorphic surface, the nature of the parent material and the soil material thickness.

Paleo-pedo-genetic processes, such as the formation of the hard calcium carbonate concretions, nodules, crust and slab, are explained by the influence of the last pluvial period. These previous paelopedogenetic processes had been associated with the isohumic formations, which were modified by the actual environmental conditions, leading to the prevailing effect of soil erosion and salinity processes.

Actually, the pedogenesis is limited, due to the arid climatic conditions. This is reflected by the weakly developed calcic horizon (soft lime segregations) formed by the slight migration of calcium carbonate. The gradual decrease of the organic matter content of soils with depth due to the actual isohumic process has been observed in profiles n° 2, 5, 7 and 12 (table I). In other profiles this phenomenon has disappeared due to the effect of wind erosion and deposition of wind blown sand. The salt affected soil formation in the ascending and intermediate profiles (S_1 and S_2 subunits as well as in the other subunits S_3 - S_4) is considered as an actual pedogenetic process. Migration of soluble salts in the depth, as it appears in many other soils (subunits B, C_2, D_1, D_2), appears also as an actual process.

From the land exploitations point of view, the following facts may be underlined :

A-unit : is very useful under dry-farming for fig and almond tress with very little management, like irrigation by run-off conserved water, or under drip irrigation, where water is available, for fruit trees and fodder crops.

B-unit : May be utilised as a dry pasture or under irrigation with a good drainage system.

C-unit : is to be used as pasture under dry conditions or irrigation with drainage, especially in C_2 subunit.

D-unit : can essentially be used for pasture, without irrigation because of its high contents of salts in ascending or intermediate profile and the shallow depth of the hard-pan (calcareous incrustation or crust).

E-unit : is only good for weak pasture.

S_1 - S_2 - subunits : needs a very high quantity of water for leaching salts and will be very expensive to be drained because of the undulated topography. They don't seem adapted to agricultural use in practice.

S_3 - S_4 - subunits : are difficult to be use, but more easy to be leached, because of their descending salt profile and to be drained due to their topographical position.

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