2 GENERAL ASPECTS OF GYPSIFEROUS SOILS

2.1 REGIONAL DISTRIBUTION

Gypsiferous soils are found in arid or semi-arid areas where gypsiferous rocks or sediments are present and rainfall is too scanty to leach gypsum out of the soil profile. The gypsiferous areas known to the authors from literature and from their own studies, are roughly indicated on the map (Fig. 1). Their estimated surface is 850,000 km^2. Gypsiferous soils are located in south-west Siberia (Soviet Geography, 1964; Momotov, 1965), in east Syria (van Liere, 1965), in north and central Iraq (Buringh, 1960) and in south-east Somalia (d'Hoore, 1964).
Gypsiferous soils can also be found in Spain (Riba Arteriu and Macau Vilar, 1962), Algeria (Durand, 1959; d'Hoore, 1964), Tunisia (Bureau, 1960; d'Hoore, 1964), Iran (Dewan and Famouri, 1964), the Soviet Republics of Georgia and Transcaucasia (Minashina, 1956; Akhvlediani, 1962, 1965) and in southern central Australia (Jackson, 1958; Jessup, 1960).

2.2 ORIGIN OF GYPSIFEROUS DEPOSITS

Gypsiferous rocks and sediments of different origin are found throughout various countries in North Africa and south-west Asia. A provisional map showing the distribution of gypsiferous rocks and sediments in Iraq has been given by Buringh (1960).
Gypsum rocks may consist of hydrated calcium sulphate, i.e. gypsum proper ($CaSO_4.2H_2O$), but also of anhydrite ($CaSO_4$). Both are crystalline; a non-crystalline form is alabaster.
Outcrops of gypsum-bearing clays or marls, as well as massive gypsum or anhydrite rocks, are known in Spain, Tunisia and Iraq. They are of Triassic, Jurassic and Cretaceous age.

During the Eocene and Oligocene, but mainly during the Miocene, solid deposits of gypsum and gypsum deposits interbedded in marls or clays, silt and sandstones, were formed in Spain, North Africa, the Middle-East and south-west Siberia. Interbedded Miocene gypsum deposits of the Lower Fars formation, are frequently found in east Syria, west and central Iraq and in south-west Iran.
In Spain, solid and interbedded gypsum deposits of the Sarmantien (Upper Miocene), and of the Ludien (transition-period Oligocene-Eocene) are found in the Ebro Valley. Gypsum deposits probably dating from the Lower Miocene are found in the Tajo Valley, south-west of Madrid.

During the Pliocene and Pleistocene, the gypsiferous rocks and sediments weathered and eroded. The debris was displaced by aeolian or fluviatile action. In some instances, the gypsum in primary deposits dissolved and was precipitated in younger formations. Sediments with such detrital or preprecipitated gypsum accumulations, either crystalline or amorphous, are called secondary gypsum deposits (Buringh, 1960). Their formation is still continuing.
Gypsum deposits of aeolian origin can be found in Tunisia (Trichet, 1963), while those in various terraces of the Euphrates and Tigris Rivers in Syria and Iraq are most likely also of this origin (Buringh, 1960; Mulders, 1969). Wind-blown gypsiferous deposits, derived from lacustrine sediments, are found in south-east Australia (Jessup, 1960).
Gypsum is transported a great distance from its origin along with the river water in which it is dissolved or broken up into particles, and is precipitated along with clay, silt and sand. Some gypsum precipitates when the river water is diverted for irrigation purposes. In sloping terrains, fragments of gypsum rocks are transported in torrential floods and deposited close to their origin (Mulders, 1969).
When the capillary fringe of gypsum-bearing groundwater is located close to the surface, gypsum may precipitate if evaporation is high. This process explains the formation of gypsum incrustations overlying water-bearing sands in the Qued R'hir and the Souf Oasis in Algeria (Durand, 1959), and would also account for part of the secondary gypsum deposits in Iraq (Buringh, 1960).
Pleistocene and Holocene salt and gypsum deposits of lacustrine origin can be found along parts of the Shotts in Algeria (Durand, 1959) and in former inland lakes in western USA.
A particular petrographic composition of the rock sometimes leads to the formation of gypsum. In large areas of south-west Siberia, a gypsiferous layer is found at depths extending from 20 to 150 cm below the soil surface.
The parent rocks are rich in sulphur compounds, e.g. pyrite. Upon oxidation, sulphuric acid is formed, which subsequently reacts with the $CaCO_3$ abundant in the rock (Rozanov, 1961). Gypsum is likewise formed in the Kirovabad Massif, Transcaucasia (Minashina, 1956) and locally in east Georgia, USSR (Akhvlediani, 1965).
The reaction of Na_2SO_4 and $CaCO_3$ may account for the formation of gypsum deposits

in the Kura Valley, Georgia, USSR (Klopotovsky, 1949). The Na_2SO_4 is leached from saline soils bordering the valley; the $CaCO_3$ originates from weathering dolorite.
From the descriptions given it can be deduced that gypsum deposits can be either pedogenetic or geogenetic. The translocation and deposition of gypsum in a soil profile as a result of percolating rainwater or capillary rise and evaporation apparently is a pedogenetic phenomenon; the formation of the Miocene gypsum deposits is a geogenetic process. Gypsum deposits originating from groundwater evaporation may be called hydrogenic.

2.3 SOIL CHARACTERISTICS

The morphology and the chemical and physical characteristics of gypsiferous soils depend to a great extent on the origin of the gypsum deposits, but also on the depth at which a proper gypsic layer occurs in the soil profile. When this layer is located 30 cm or more below the surface, the top layer of the soil often has morphological and physico-chemical characteristics similar to those of the non-gypsiferous soils encountered in the same pedogenetic condition, e.g. Chestnut, Chernozem or Sierozem soils (Rozanov, 1961, Kurmangaliev, 1966).
The characteristics of gypsiferous soils are also determined by the fact that gypsum is easily re-distributed within the soil profile as a result of the alternating influence of rainfall and evapotranspiration. When a gypsic layer is situated close to or at the soil surface, dew formation can also play an important role in the migration of gypsum (Bureau and Roederer, 1960).
The varying origin of gypsiferous deposits and the easy re-distribution of gypsum in the soil may result in a great variance in the morphology of the soil profile, as is illustrated by the descriptions of two different soil profiles from the Euphrates Basin (see Annex).
A gypsic layer can have either a powdery or a sandy appearance, depending on the size of the gypsum crystals, which may vary from 50 to over 2,000 microns. Gypsum deposits formed by the oxidation of sulphur components present in parent rocks are often composed of very fine crystals (Rozanov, 1961). When gypsum redistributes within the soil profile, it may take the form of pockets composed of very fine gypsum crystals, lumps consisting of sand and soil particles cemented by gypsum, gypsum rosettes, or hard horizontal crusts. Vertical gypsum crusts also occur (Buringh, 1960). These have a polygonal pattern and consist of two vertical plates of pure gypsum, extending to a depth of sometimes up to one meter and separated by a thin layer of soil. The genesis of such crusts is not fully understood. In contrast with horizontal gypsum crusts, vertical crusts are very resistant to disintegration.
Powdery gypsic layers are characterized by a low bulk density and a soft consistence. The low bulk density is due to a relatively low specific weight of gypsum, e.g. 2.3 gr per cm^3, in combination with an occasional high porosity. Lumps and crusts, however, are hard

and can have a low porosity. The porosity of the crusts probably depends on the degree of wetting and drying during crust formation (Mulders, 1969).

Gypsum accumulations are seldom composed of pure gypsum, but are usually a mixture of gypsum, $CaCO_3$ and or soil particles. Gypsum crystals are sometimes coated with a precipitate of $CaCO_3$.

Gypsiferous soils cannot always be discerned visually during field work. (See for instance Profile 1 in the Annex). The gypsum content is often difficult to estimate and should be determined in the laboratory. The quantitative acetone method, as proposed by Richards et al. (1954), is appropriate for this purpose. As the solubility of gypsum is only about 2.6 gr/1, (although the solubility varies somewhat with the concentration and the composition of the soil solution), a 1:1 soil-water extract would dissolve only about 0.25 weight % of gypsum in a soil sample. The soil-water extract should therefore be very dilute when high gypsum percentages are involved, e.g. 40 % gypsum, the ratio soil-water should be at least 1:160. The acetone method can also be used to determine gypsum qualitatively. It can be applied in the field as a quicktest on the presence of gypsum in the soil.

2.4 SOIL CLASSIFICATION

Many publications on soil classification mention gypsiferous soils. It would appear, however, that in the various systems, gypsum in the soil is often considered a criterion only at lower levels of the classification. Four different types of gypsiferous soils in Spain were described by Kubiena (1953), who classified them as sub-groups of some great soil groups, viz.. Solonchaks, Desert Soils, Rendzinas and Sierozems. In the 'gypsum Solonchak' the gypsum has precipitated by evaporation from shallow groundwater. The 'gypsum crust yerma', a Desert Soil, is a raw mineral soil with a hard crust on the soil surface, the chief cementing agent being gypsum. The 'gypsiferous Xerorendzina' is formed primarily in mountainous areas on solid gypsiferous rocks, whereas 'gypsiferous Sierozems' are formed on loose, gypsum-bearing parent material.

Gypsiferous soils in the Ebro Valley, Spain, were grouped by Albareda et al. (1961) with the Sierozems and Rendzinas: 'marly gypsum Sierozem' and 'gypseous Xerorendzinas'. In the 'marly Sierozem' the decomposing gypsum marl is found at a depth of 40 to 50 cm below soil surface and in the 'gypseous Xerorendzinas' at a depth of approximately 20 cm.

Bureau and Roederer (1960) studied soils in the area around Gabès (Tunisia) and grouped gypsiferous soils either with the Calcimorphic or with the Hydromorphic soils. Le Houerou (1960) included gypsiferous soils in southern Tunisia with the 'Well-developed Soils', 'Non- or slightly developed Soils' and 'Paleosoils', respectively.

In Iraq, gypsiferous soils are found within the great soil groups of the Sierozems, Reddish-brown soils, Lithosols, Regosols and occasionally among the Alluvial Soils (Buringh, 1960).

In the USSR, gypsiferous soils have been classified as 'gypsum-bearing Sierozems' (Rozanov, 1961; Kurmangaliev, 1966) and as 'structural Sierozems' (Rozanov, 1961). On the soil map of Georgia, USSR, shallow soils on solid gypsum rock are named 'gahza' (Akhvlediani, 1962).

In the 'Seventh Approximation', the newest soil classificaton system in the USA (Soil Survey Staff, 1960), a 'gypsic horizon' is defined as a layer secondarily enriched with calcium sulphate. The 'gypsic horizon' should have a thickness of at least 15 cm and contain at least 5 % more than the underlying layer; the product of the thickness of the gypsum enriched layer in centimeters and the percentage of gypsum should be more than 150. Evidently a shallow soil on solid gypsum rock will not normally contain a 'gypsic horizon', even if it contains considerably more than 10 % gypsum. Nor does a 'gypsic horizon' in sedimentary soils lead to a special classification. Its presence is indeed diagnostic at the lower levels of classification, but then it is used indiscriminately with a similarly defined 'calcic horizon'. Thus most gypsiferous sedimentary soils belong to the Aridisol order of classification, forming part of the Calciorthid great group. Mulders (1969), in his classification of the soils in the Balikh Basin (Syria), introduces the name Gypsiorthids.
In a recent supplement to the 'Seventh Approximation' (Soil Survey Staff, 1967), however, the term 'gypsic' is also applied to a mineralogical class for the grouping of soils at 'family' level. In this case the gypsum content should be more than 35 % of the sum of carbonates and gypsum, and this sum itself more than 40 % by weight. Neither the depth of occurrence, the thickness of the layer concerned, nor the 'enrichment' aspect reappears in this definition. In practice 14 % is the critical value. This value is used in the present paper to distinguish between 'gypsic' and 'non-gypsic' layers.
The present classifications of gypsiferous soils do not give adequate recognition to the characteristics determining the agricultural value of gypsiferous soils. These characteristics, as will be shown in the following chapters, are the depth at which a gypsiferous layer is found, its percentage of gypsum and its consistence (powdery, crusty, stony).

A gypsiferous soil in the Euphrates valley, Syria.
The surface contains less than 1 %; the gypsum content below a depth of 37 cm is 45 % (see description profile no 2 in Annex).