TWO EXAMPLES OF PHYSIOGRAPHICALLY RELATED CALCIC CAMBISOLS FROM THE EBRO BASIN IN NORTH-EASTERN SPAIN

(part of a I.S.R.I.C. Soil Monolith Paper)

By

J. Boixadera

Spain

1985

MSc - COURSE IN SOIL SCIENCE AND WATER MANAGEMENT

AGRICULTURAL UNIVERSITY

WAGENINGEN - THE NETHERLANDS

TWO EXAMPLES OF PHYSIOGRAPHICALLY RELATED CALCIC CAMBISOLS FROM THE EBRO BASIN IN NORTH-EASTERN SPAIN

(part of a I.S.R.I.C. Soil Monolith Paper)

A major thesis presented in partial fulfilment
of the requirements for the degree of
Master of Science

By
J. Boixadera
Spain
1985

Approved by:
Dr. W.G. Sombroek

M.SC.-COURSE IN SOIL SCIENCE AND WATER MANAGEMENT,
AGRICULTURAL UNIVERSITY, WAGENINGEN, THE NETHERLANDS

Not for publication;
for internal use only.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This paper describes the central concept of Calcic Cambisols, their world distribution, the associated soils and their agricultural use. Two soils represented by soil monoliths numbers E-19 and E-20 of the ISRIC* collection are described in the main part of the paper. The soils are Calcic Cambisols (profile E-19 a Calcixerollic Xerochrept, coarse-loamy, mixed, mesic; profile E-20 a Petrocalcic Xerochrept, fine-loamy, carbonatic, mesic) and their setting, their field appearance, their genesis and their classification are discussed.

They were sampled and described at La Segarra, NE of the Ebro Basin (Spain) (fig. 1 and 2) by the author and the team of the Dep. Soils and Climate of the ETSIA, Lleida, in October 1984.

Interpretation of data with respect to Land Evaluation for some relevant Land Utilization Types is beyond the scope of this M.Sc.-thesis, but it is the author's intent to deal with the Land Evaluation of Calcic Cambisols in a separate paper. Also, the work in execution by ETSIA will provide in due course a soil map of La Segarra which will show more clearly the soil pattern where the two studied Calcic Cambisols were collected.

* International Soil Reference and Information Centre, Wageningen, the Netherlands.

1. GENERAL INFORMATION AND SETTING

1.1 General information on the Calcic Cambisols

1.1.1 Central concept of the soil unit

Calcic Cambisols are well drained, relatively young soils, usually developed on calcareous (parent) materials and occurring under subhumid to semi-arid climatic conditions. Their most salient characteristic is a redistribution of lime and/or gypsum in the profile, showing up in an appreciable amount of calcium carbonate accumulations immediately below a structured subsurface layer ("cambic B horizon") or an acid-humic surface layer ("umbric A horizon").

In the legend of the FAO-UNESCO Soil Map of the World (FAO-Unesco, 1974) Cambisols are defined as soils having a cambic B horizon and (unless buried by more than 50 cm or more new material) no diagnostic horizons other than an ochric or an umbric A horizon, a calcic or a gypsic horizon (the cambic B horizon may be lacking when an umbric A horizon is present which is thicker than 25 cm); lacking high salinity; lacking the characteristics diagnostic for Vertisols or Andosols; lacking an aridic moisture regime; lacking hydromorphic properties within 50 cm of the surface.

Cambisols differ from the other soils having a cambic B horizon and/or an umbric A horizon as follows:

- -from Solonchaks in that Cambisols lack high salinity;
- -from Gleysols in that Cambisols lack hydromorphic properties within 50 cm of the surface;
- -from Andosols in that Cambisols do not have to a depth of 35 cm or more one or both: (a) a bulk density (at 1/3 bar retention) of the fine earth fraction less than 0.85 g/cm^3 and the exchange complex dominated by amorphous material; (b) 60 percent or more vitric volcanic ash, cinders or other vitric pyroclastic material in the silt, sand and gravel fractions;
- -from Rankers in that Cambisols have an umbric A horizon thicker than 25 cm;
- -from Ferralsols in that Cambisols do not have an oxic B horizon;
- -from Planosols in that Cambisols do not have an albic E horizon overlaying a slowly permeable horizon within 125 cm of the surface;
- -from Greyzems, Chernozems, Kartanozems and Phaeozems in that Cambisols lack a mollic epipedon;
- -from Xerosols and Yermosols in that Cambisols do not have an aridic moisture regime;
- -from Nitosols, Acrisols and Luvisols in that Cambisols do not have an argillic B horizon.

The soil unit Calcic Cambisols includes the Cambisols having one or more of the following characteristics: a calcic horizon, a gypsic horizon or concentrations of soft powdery lime within 125 cm of the surface when the weighted average textural class is coarse, within 90 cm for medium textures, within 75 cm for fine textures; calcareous at least between 20 and 50 cm from the surface.

FIGURE 1. Location map Sc. 1:20.000.000

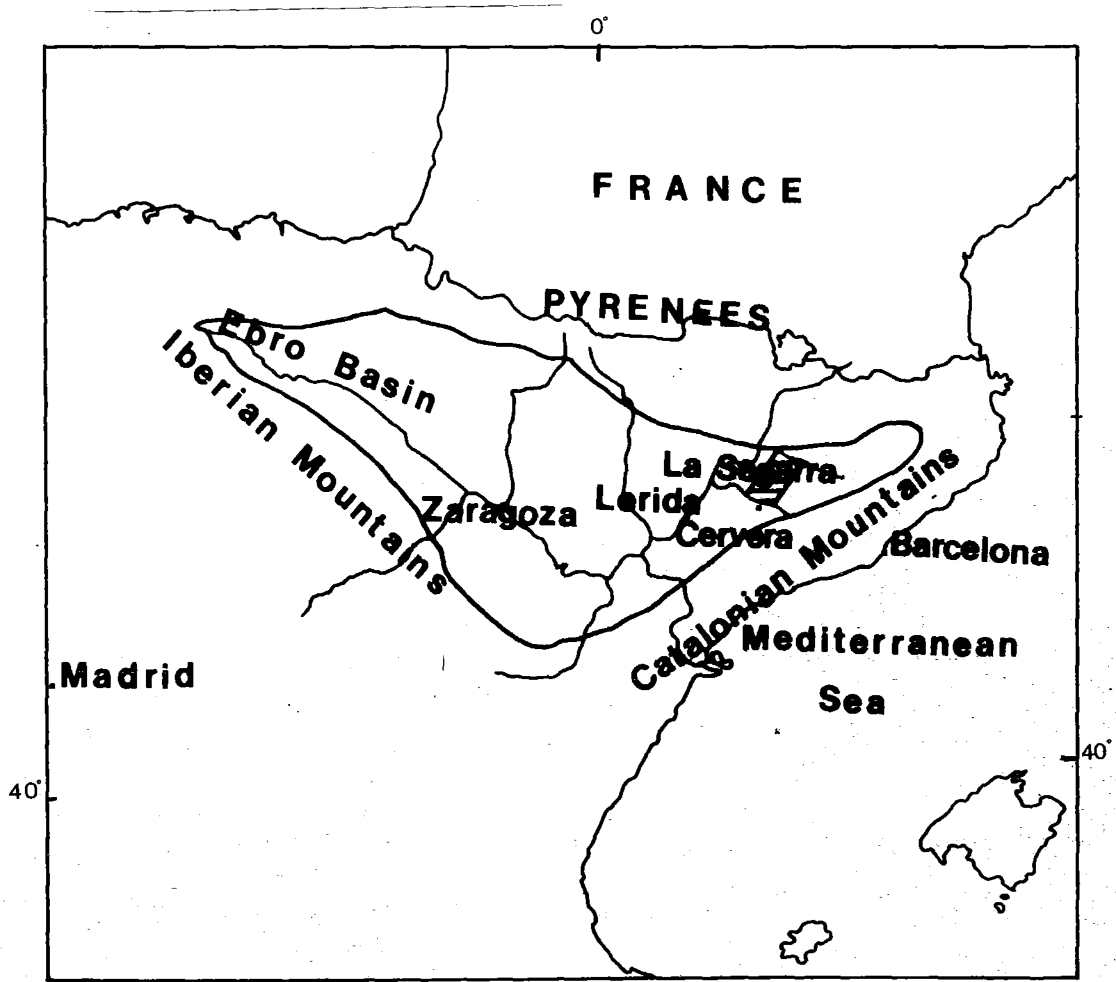


FIGURE 2. The Ebro Basin and La Segarra area, NE of Spain

1.1.2 Regional and global extension. Associated soils.

The central concept of Calcic Cambisols includes soils showing some degree of development, with a cambic or umbric horizon, and in addition leaching and accumulation of carbonates and/or gypsum. These accumulations have a very different stage of development, ranging from the early stages of soft powdery lime to late ones with indurated calcretes. This results in the situation that Calcic Cambisols are found in geomorphic surfaces of ages from Pliocene - Pleistocene to Holocene and in all moisture regimes (Soil Survey Staff, 1975), excluding aridic.

The Soil Map of the World (FAO-UNESCO, Volumes II through X, published between 1971 to 1981) reports their occurrence in many topographic positions, but mainly in flat or hilly areas, although they are extensive in certain mountain rangelands. They are medium or fine textured, except in some areas in the tropics and subtropics where they can be coarse textured.

Parent materials have a variety of ages, from Paleozoic to Quaternary. They include igneous rocks and basalts, andesite and granite or Tertiary - recent volcanics: phenolite, nephelinite, pyroclastics, tuff; but they are mainly metamorphic and sedimentary: schist, shale, quartzite, clay, calcareous clay, marl, chalk, marly limestone, limestone, dolomite, flysch, calcareous sandstone, sandstone, gypsiferous marl, gypsum, coral limestone, loess, deposits from aeolian, lagoonal and lacustrine origin, and Pleistocene and subrecent alluvium.

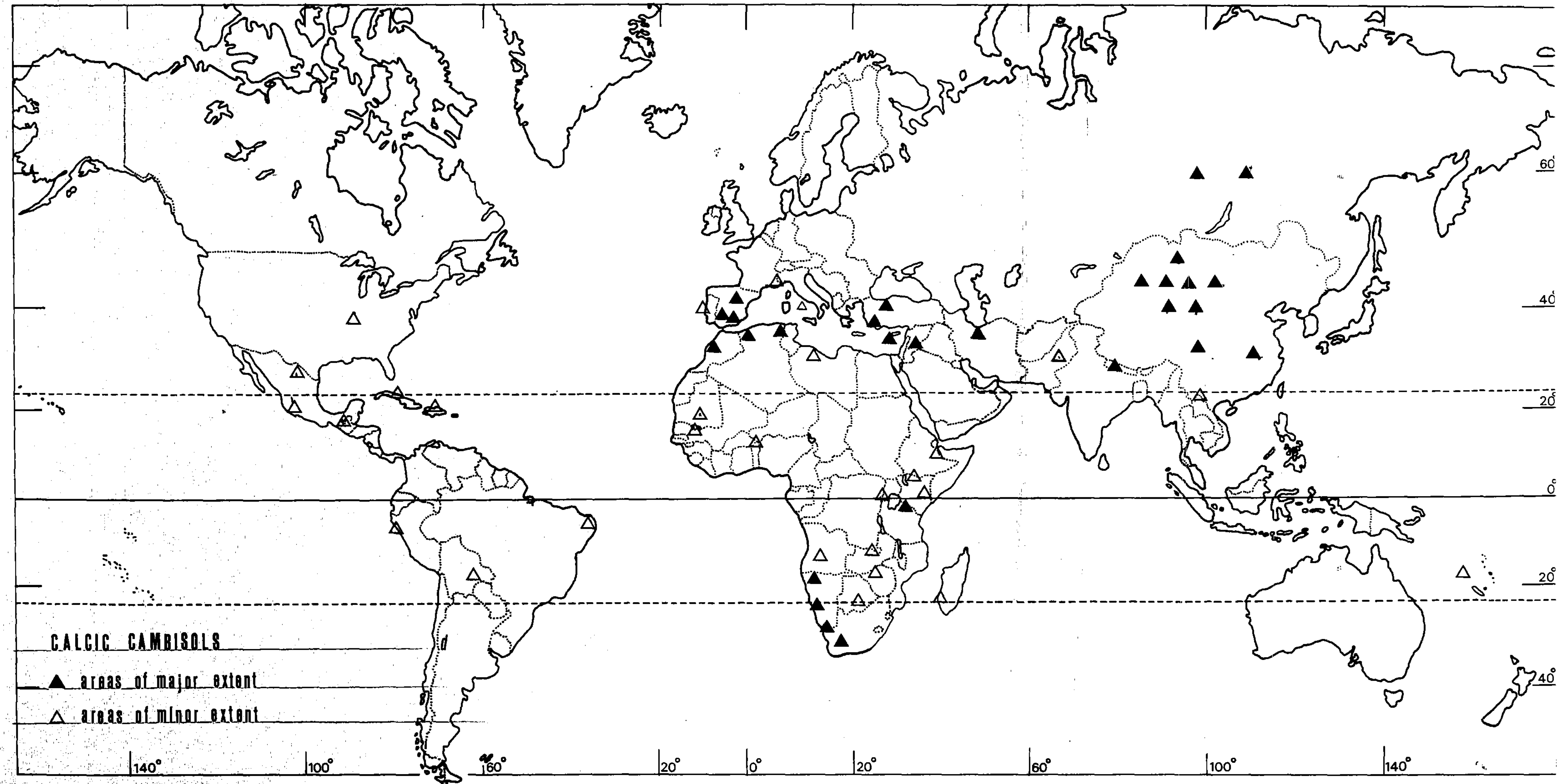
The total extent of Calcic Cambisols has been estimated at about 730,000 km^2 ($\simeq$ 0.55% of the total world's land) from the FAO's Agroecological Zones Project (computer print-outs at ISRIC) and from the various volumes of the Soil Map of the World (FAO-UNESCO, 1971 to 1981). The largest areas are in China, southern Africa and around the Mediterranean Sea (fig. 3).

In North America (map unit Bk6-3a, FAO-UNESCO, Volume II, 1975) Calcic Cambisols are almost absent; they are only reported in Alabama in a dissected, gently sloping upland of limestone, where they are associated with Chromic Vertisols.

In Central America they are reported in the subhumid mountains of Central Mexico (units Bk5-2a and Bk7-2bc, FAO-UNESCO, Volume III, 1975) in association with Rendzinas, Lithosols, Luvisols, Phaeozems and some Vertisol inclusions, having in many cases lithic phases. As a subdominant soil they are in association in areas of Chromic Luvisols. The presence of Calcic Cambisols has been reported also from Cuba, Guatemala, Haiti and Dominican Republic, very often with a lithic phase.

In South America they are often reported (FAO-UNESCO, Volume IV, 1971) in Ecuador (map unit Bk1-3a) where the Calcic Cambisols are in association with Ferric Luvisols. In the same country, they are reported as subdominant soil with Chromic Luvisols. Calcic Cambisols have been described in Bolivia (map units Bk2-b, Bk2-c) associated with Lithosols. In northeast Brazil they are coarse textured and subdominant in units with Ferric Arenosols or Eutric Regosols.

FIGURE 3. World distribution of Calcic Cambisols (adapted from FAO-Unesco Soil Map of the World and other sources



In Europe (FAO-UNESCO, Volume V, 1981) Calcic Cambisols are dominant in Cyprus and Spain. They also occur in small areas in France, Italy and Portugal. In Cyprus (map unit Bk35-2/3ab) they are developed in limestone, have a lithic phase and are associated with Vertic Cambisols and Chromic Vertisols. Sardegna in Italy (map unit Bk32-2/3c) has a very shallow Calcic Cambisol owing to a lithic phase. In Portugal (map unit Bk47-2/3b) they are in association with Calcaric Regosols and other Cambisols. Spain has a large extension of Calcic Cambisols, mainly in the eastern part (map units Bk45-2bc, Bk46-2a, Bk47-2/3b, Bk48-2/3b) developed from different calcareous parent materials; they have stony, lithic, petrocalcic and saline phases; the main associated soils are Rendzinas, Lithosols, Calcaric Regosols, Gleyic Solonchaks and inclusions of Kartanozems, Phaeozems and Luvisols.

In Africa (FAO-UNESCO, Volume VI, 1977) Calcic Cambisols are extensive mainly in the northeast and in the southeast. They have been reported in Canary Islands, Angola, Botswana, Ethiopia, Kenya, Lybia, Madagascar, Mauritania, Niger, Nigeria, Senegal, Somalia, Uganda, Zambia and Zimbabwe, where they are not very extensive. In Algeria, Morocco and Tunisia (map units Bk2-bc, Bk2-2ab, Bk2-2b, Bk2-2bc, Bk6-2/3d, Bk10-1ab, Bk10-2b, Bk11-1b, Bk13-2ab, Bk14-2b, Bk14-2bc, Bk14-2c, Bk20-2ab) Calcic Cambisols are widespread near the Mediterranean Sea; they show petrocalcic phases in some parts and the number of associated soils is very large: Lithosols, Rendzinas, Calcaric Regosols, Chromic Cambisols, Calcic Kartanozems, Gypsic Xerosols, Calcic Xerosols and Chromic Luvisols. An area of Calcic Cambisols occurs at the southeast of the Great Lakes in Tanzania (map units Bk25-2a, Bk26-2/3a, Bk27-2ab, Bk28-2b, Bk29-2ab) with petrocalcic phases in several places. The main associated soils are Eutric, Gleyic and Chromic Cambisols, Calcic Luvisols and Eutric Nitosols. South Africa and Namibia have Calcic Cambisols as subdominant soil in association with Calcic Xerosols and Lithosols (map unit Xk24-2ab)

In (South) Asia Calcic Cambisols are dominant in areas of Turkey (map units Bk45-2bc, Bk49-2c, FAO-UNESCO, Volume VII, 1977), where they form an arc from the Aegean to the Black Sea, being associated with Rendzinas, Lithosols and Chromic Luvisols. Calcic Cambisols have been described in many other countries of the area: Iraq, Israel, Jordan, Burma, Pakistan, Nepal and Laos. They also occur in a fair extension in India (map units Bk34-2a and Bk40-2a), where in the northern Indo-Gangetic Plain they are associated with Calcaric and Eutric Fluvisols and Eutric Cambisols. In Iran they are common in the northern part of the Elbruz Mountains and along the coastal plain of the Caspian Sea, associated with Eutric Regosols and Cambisols (map unit Bk37-2/3c). In Lebanon (map units Bk33-c, Bk34-3b) they are present as dominant soils in landscapes where Lithosols, Rendzinas, Chromic Vertisols and Luvisols are also present.

In North and Central Asia (FAO-UNESCO, Volume VIII, 1978) occurs the largest area of Calcic Cambisols in the world. In China (map units Bk36-2b, Bk42-2b, Bk44-3a) they are mainly in the Chin Ling region wich borders the North China Plain on the west; they are associated with Luvisols and Xerosols. They are present also in other associations in the mountain areas in the central Yakutian depression as subdominant soils, Gelic Cambisols being the dominant ones and Soladic Planosols, Gleyic Solonetz, Histosols and Mollic Gleysols other associated soils.

In southeast Asia (FAO-UNESCO, Volume IX, 1979) Calcic Cambisols have been reported in the Tonkin massif of Vietnam, the eastern mountains of Laos and Vietnam and the western highlands of Thailand. They are developed in a massive, locally dolomitic limestone, Lithosols being the main soils and Chromic Luvisols and Calcic Cambisols subdominant.

In Australasia (FAO-UNESCO, Volume X, 1978) Calcic Cambisols are very rare, having been reported only in New Hebridas and Fiji Islands (map units Bk11-3b, Bk43-3a and Bk43-3b). They are there associated with Lithosols and Calcaric regosols; as subdominant soils they are associated with Ferralic Cambisols. The parent materials are volcanic products and coral limestone.

1.1.3 Regional and global agricultural use

No general pattern of landuse can be drawn for the Calcic Cambisols because the wide variety of climates and landscapes where they occur (FAO-UNESCO, Volumes II through X, 1971-81).

Calcic Cambisols in North America are mainly used for forage, but cotton, soybean and maize are grown also. In Mexico they are under extensive grazing in the natural grasslands that develope when the xerophytic woodland has been destroyed; where slopes are adequate they can be irrigated, yielding regular crops of maize by mechanized farming. However, because they are on strongly rolling to hilly landscapes, they are highly erodable and irrigation is difficult.

Coconuts are grown in certain areas on Calcic Cambisols which are mainly under forest, grass and shrubs in Fiji Islands and New Hebridas.

The natural vegetation of Calcic Cambisols in Iran is oak forest. The north facing slopes of Elbruz Mountains are used for rice. In the southern parts almond and pistacho plantations are important.

In the Ganges Plain of India these soils are mainly used under irrigated wheat, rice, sugarcane, pulses and fodder crops.

The area where Calcic Cambisols are found in the semi-arid steppe of Central China is badly eroded by water and wind. Sparse rainfall causes low yields of quickly growing crops, such as certain wheat, sorghum and millet varieties adapted to that environment. Owing to the dissected landscape large irrigation is not possible and farming flourishes only in the deep river valleys and in some southern areas where the rainfall is higher.

Siberian larches and pines, which are frost resistant and have a not - to - deep root system, are the landuse of the Calcic Cambisols associated with the Gelic Cambisols in Central Siberia. Some areas are used for farming with crops of short growing season, and also for grazing and other fodder crops.

Subsistence agriculture based on sorghum, millet and extensive winter grazing are practiced on Calcic Cambisols in Senegal and Mauritania, where they have a semi-arid tropical climate.

Grassy savanna of Hyparshevia, Themeda and Panicum is the cover of the Calcic Cambisols in Tanzania, Uganda and Kenya. Annual subsistence cropping is practiced, with millet, sorghum, beans, cassava and sweet potatoes. Shifting cultivation is combined with some livestock raising.

Under subtropical Mediterranean conditions, that is a dry climate, they are found in Morocco, Algeria and Tunesia and it is the texture, the topography and the depth to a petrocalcic horizon that determines the landuse. Winter cereals and extensive grazing are some of these landuses, but olives, figs and other Mediterranean crops are grown. Under irrigation citrus is grown, but they suffer quite often from chlorosis due to the high lime content of these soils.

In Lebanon, with a moist Mediterranean climate, olives, grapes and wheat are grown without irrigation, whereas apple, citrus and vegetable crops are irrigated.

Also under Mediterranean climate Calcic Cambisols occur in Portugal, Spain and Turkey under dry climates; slopes, susceptability to erosion and moisture stress being the major limitations. Owing to the last limitation many of them are irrigated. In south Spain on rolling to hilly terrain they are devoted to cereals, fruits and vineyard, and to rough grazing and forestry; it is worthy to mention that durum wheat is concentrated on those soils. Calcic Cambisols in the northeast of Spain are used under arable cropping, including cereals, irrigated fodder crops and cereals, horticulture, irrigated and rainfed fruits, while in the east forestry is extensive. A petrocalcic phase on level topography which occurs frequently in Spain, has a high fruit and vine concentration in addition to cereals.

Portugal has Calcic Cambisols in hilly terrain under Mediterranean marine conditions. Vine and fruit together with cereals are intensively cultivated.

In Turkey Calcic Cambisols are under continental Mediterranean climate on hilly and mountainous topography. They are devoted to cereals, grazing but also to fruit and forestry. A lithic phase occurs on mountainous topography in the Black Sea region of Turkey, being used for forestry, rough grazing and arable cropping.

1.2 Regional environmental setting

1.2.1 Climate

The climate of the La Segarra has been studied by Pomar (1982), who carried out a work with data from several meteorological stations. The results are summarized here and extra information is added when relevant aspects are lacking. No meteorological records from the soil sites are available and the ones from the nearest meteorological stations have been chosen to characterize the climate:

- Cervera, 13 km SW from the sites, 540 m high above sea level, and
- Rocallaura, 25 km SSW, 660 m above sea level.

For the former pluviometric and thermometric records are available; the latter has only precipitation records. The heights of the stations are in the range of heights of the area discussed here.

Monthly and yearly temperature and evapotranspiration data for Cervera are shown in Table 1; precipitation data for both stations are shown in Table 2.

The mean monthly temperature shows a large seasonal variation, and it ranges from 4.0°C in December and January to 23.8°C in July. The extremes have even a large variation because the mean monthly maximum temperature goes from 7.7°C in December to 31.1°C in July and the mean monthly minimum temperature goes from 0.1°C in January to 16.5°C in July. The absolute maximum temperature was registered also in July (40°C) and the absolute minimum temperature in December (-9°C). The period without frost, according to Emberger criterion, goes from the end of April to the end of October.

Rainfall has a seasonal distribution, with a maximum in spring (156 mm in Rocallaura, 151 mm in Cervera) and a minimum in winter (115 mm in Rocallaura, 91 mm in Cervera) with intermediate values for summer and autumn. The yearly distribution is almost normal (mean ≃ median) and it has some more skew in Cervera. The interannual range of variation (231 to 760 mm per year in Rocallaura and 227 to 660 mm per year in Cervera) and the variation coefficient (CV = 28.5 in Rocallaura, CV = 22.4 in Cervera) points out the strong interannual variation of the rain in the area; the monthly variation is larger, CV being always larger than 50% and in some months larger than 100%. The changes in amount of rainfall with increasing height above sea level shows the expected pattern of increasing precipitation with increasing elevation.

According to the Agroecological Zone Concept the growing period is calculated on a single water balance basis, comparing P and PET. The beginning of the growing season is taken as the time when P equals or exceeds half potential evapotranspiration after a dry period. When the condition of precipitation surplus ceases, crops will not perish because they can draw water from the stored soil moisture. Although in the AEZ project the available soil moisture was set at 100 mm, in the present case P - PE in the humid period is only 55 mm in Cervera and 70 mm in Rocallaura. Both values are smaller than the available water holding capacity (AWC), even for shallow rooted crops (Appendix III).

Values of PE according to Thorntwaite formula are very conservative. Instead of them, values computed with the Blanney-Criddle modified method (FAO, 1977) are used in the calculation of the growing period. Unpublished data from the Servicio Meteorologico Nacional has been used to compute PE according to Blanney-Criddle.

In Cervera the growing period begins (P = 0.5 PE) on 11th of October (Figure 4) and it ends 31st of March. The 55 mm stored are evaporated at a rate of 3.7 mm/day, giving the end of the growing period by 15th of April. Because the temperature is below 5°C from 5th of December to 4th of February the growing period has a length of 126 days.

The growing period starts in Rocallaura by the 15th of October, P equals 0.5 PE again by the 8th of April and to evaporate 70 mm takes 19 days, giving the end of the growing period by the 27th of April. By substracting again the period when growth is limited by temperature, the length of the growing period is 148 days.

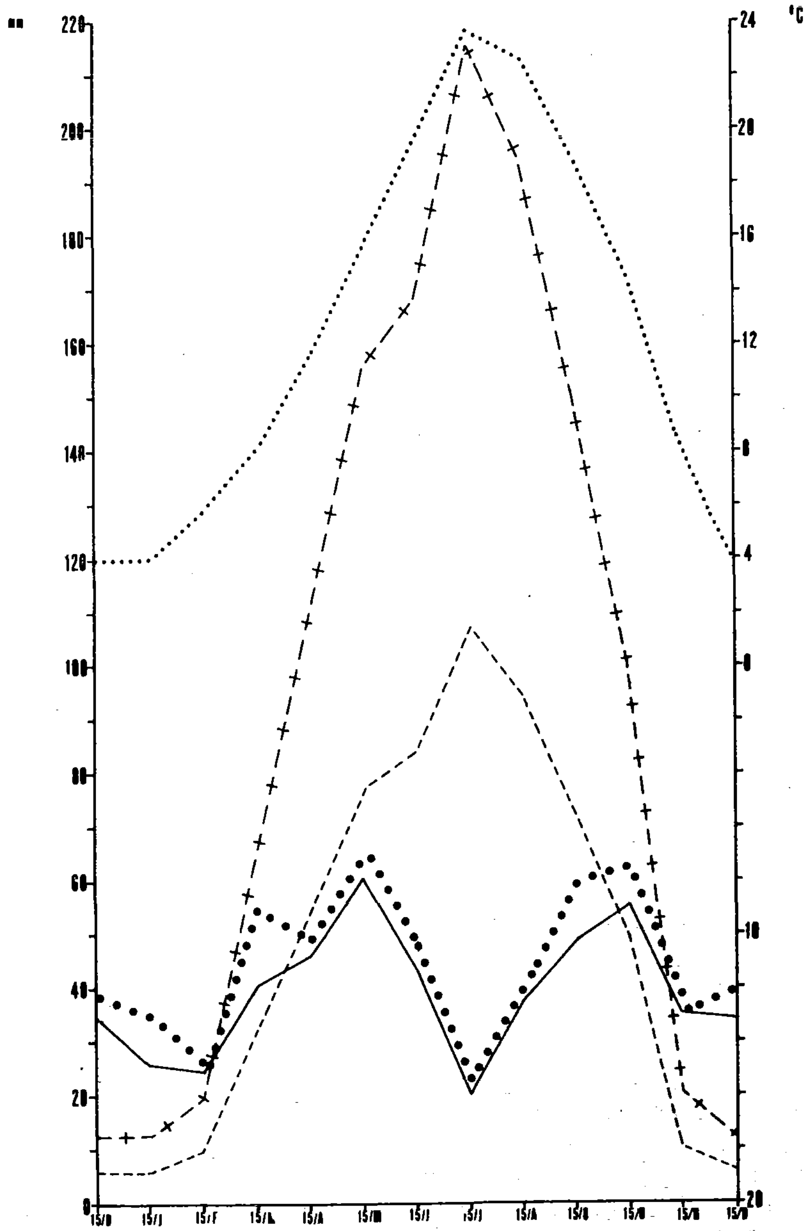
TABLE 1. Monthly temperature and evapotranspiration for Cervera. (After: Pomar 1982, modified)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
						Mean monthly temperature in °C							
Maximum	8.0	10.9	13.6	17.4	21.8	26.8	31.1	29.4	24.9	19.8	12.3	7.7	18.6
Mean	4.0	5.8	8.1	11.5	15.4	19.9	23.8	22.7	19.0	14.4	8.1	4.0	13.0
Minimum	0.1	0.7	2.6	5.5	9.1	13.0	16.5	16.0	13.0	9.0	3.9	0.6	7.5
						Evapotranspiration in mm per month							
T.	8.2	13.5	26.9	47.1	80.3	114.7	148.5	129.6	88.3	55.2	21.4	8.2	74.2
B.-C.	12.4	19.6	65.1	111	155	168.6	215	189	144	100.5	21.0	12.0	121.3

T. = Thornthwaite
B.-C. = Blanney-Criddle (modified, FAO, 1977)

TABLE 2. Monthly rainfall for Cervera and Rocallaura. (After: Pomar, 1982)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
						Mean monthly rainfall in mm per month							
Rocall.	35.4	24.9	54.6	48.9	64.5	43.0	22.7	38.2	59.8	63.8	35.9	38.3	530
Cervera	25.8	24.3	40.4	46.7	60.4	43.6	20.3	37.7	48.5	55.1	35.5	34.8	473
						Median monthly rainfall in mm per month							
Rocall.	25.3	24.6	40.1	35.5	58.2	30.7	19.1	24.1	40.5	57.5	28.5	27.0	524
Cervera	24.0	26.5	32.2	39.8	46.0	36.0	16.6	34.7	43.7	37.7	32.2	29.2	490
						Average number of rainfall days							
Rocall.	4.3	3.4	4.8	5.6	6.4	5.3	2.6	3.2	4.0	4.8	4.7	3.1	



mean monthly precipitation Rocallaura,mm
" " " Cervera,mm
" " potential evapotranspiration (Blanney-Criddle),mm
" " 0.5 evapotranspiration (Blanney- Criddle),mm
" " temperature, C

FIGURE 4. Monthly rainfall, temperature, evapotranspiration and 0.5 evapotranspiration of Cervera and Rocallaura.

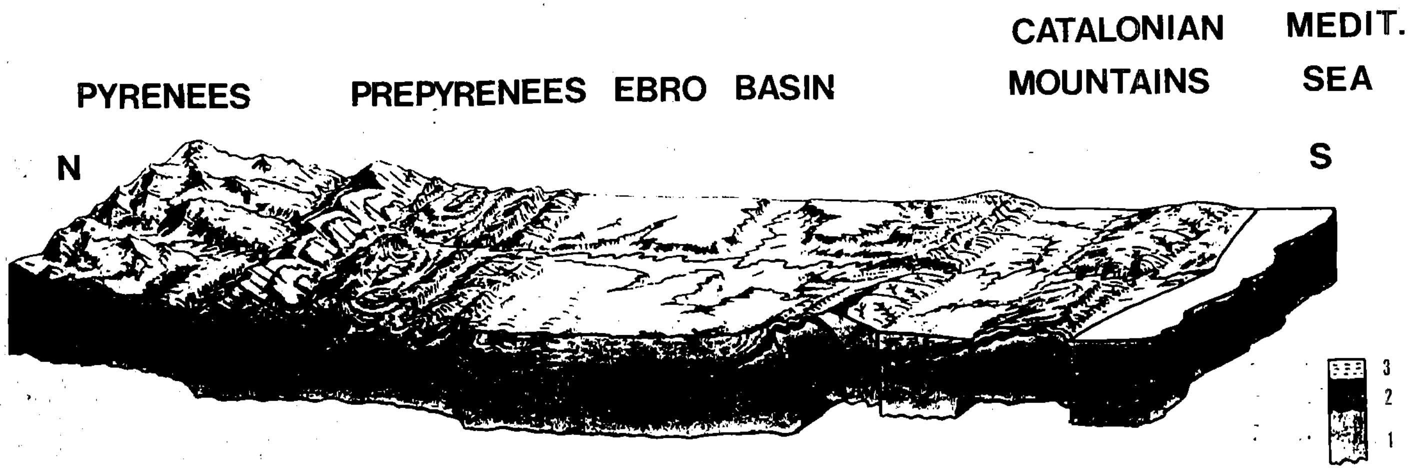


FIGURE 5. Cross section of the Eastern part of the Ebro Basin
(Adapted from Solè Sabaris, 1958)

1 PRIMARY
2 SECONDARY
3 TERTIARY

Taking into account that the sites conditions resemble more the possible situation of Rocallaura than Cervera, the length of the growing period on the sites will be around 150 days according to the AEZ concept.

Fog is a very common event from November to April, standing for several days, mainly in the valleys and lower places. There are no records available about snow, but it snows once many years.

According to Thornthwaite the climate is: dry climate, with no or little surplus of water, mesothermic. Using Papadakis classification it is a mild Mediterranean. Köppen climatic classification gives a Csa or Mild humid climate, with a dry, hot summer. It is a semi-arid climate according to FAO-UNESCO.

1.2.2 Geology

The description which follows is taken from Sole Sabaris (1958), Riba (1976) for the general parts and from Julia and Marques (1981) for the information about La Segarra.

The Ebro Valley is situated in the northeast of Spain, between several mountain rangelands. The Pyrenees are closing the depression in the north side, the Iberian Mountains in the southwest and the Catalonian Mountains in the east. That basin was formed in the middle Eocene at the same moment that the Pyrenees were uplifted. From the very beginning a very intense sedimentation started in a close sea: near the mountains the materials were coarse (sandstones, conglomerates) and going to the center of the depression clays, marls and dissolved materials (calcium carbonate, gypsum and other salts) were deposited. Later on, overlaying those evaporites, a thick cover of materials up to 2.5 km was sedimentated in the transition Eocene-Oligocene in a fluvio-continental environment, being molassas near the borders and changing to limestone and marlaceous clays to the center.

The deposition of sediments is horizontal or subhorizontal and almost free of foldings, but several anticlines were developed in the northern part, due to the evaporites in the Miocene. They are WNW-ESE the most, but another series of minor ones is present perpendicular to the first system, more or less NE-SW. Prior to the formation of the anticlines, during the Upper Eocene, the sediments closer to the Pyrenees and the Catalonian Mountains were strongly folded due to late tectonic movements from the Alpidic orogenesis giving rise to minor mountainous systems which are between the depression itself and the major mountain chains.

Figure 5 is an attempt to give a summary of the structure and materials in the eastern part of the Ebro Valley.

The area where the profiles have been collected belongs to a district called La Segarra. It is situated in the eastern part of the basin, but still far from the borders, where the coarser fragments are dominant. Only a major deformation occurs in the materials, and it is the aforementioned anticline situated in the north of the area, with a direction WNW-SE, but several other local deformations are present. Three main parts from the geological-lithological point of view can be discriminated in La Segarra:

a) The core of the empty anticline. That anticline was developed due to the pressions of the sediments overlaying the gypsum and the other salts. The drainage system of the Llobregos River has emptied the anticline, giving rise to an inverted landscape, the anticline core being a low lying area. No stratification can be seen on it. The gypsum is rather impure and it contains also anhidrite and other rich calcium carbonate materials as clay and silt.

b) The materials south of the anticline are somewhat bended, giving rise to a cuesta landscape due to the alternating beds of hard and soft rocks. The bending decreases very sharply when the distance from the anticline core increases. That area can be divided in two parts:
   1) The western part where the materials are alternating beds of $CaCO_3$ cemented sandstones, and silt and clay with different degrees of cementation.
   2) The specific area where the profiles are coming from. That area is at both sides of Sio River, but mainly corresponds to stretch between that river and the main front cuesta. It has as geological substratum beds of limestone and siltstone. The silt is consolidated and somewhat cemented by $CaCO_3$, ranging in some cases to marl and calcareous marl.

c) An undulating area to the southwest, where the cuestas are not present. The materials are subhorizontal sandstones, conglomerates and clays, with some cover from the Quaternary on the bottom valleys. The drainage is not well defined and some remanent surfaces, developed in cemented limestone gravels, are present.

It is worthy to mention that in the Quaternary, during the glacial periods, the Pyrenees were covered by ice from 2000-3000 meters up, and from 500-600 m up to that height a periglacial environment existed (Sole Sabaris, 1958). There is no agreement among authors (Calvet and Gallart, 1979) about whether the studied area - which is above 600 m - had that periglacial environment or not.

1.2.3 Physiography and hydrology

The site where the soils occur is an area of cuestas, several km far from the anticline core referred before. The landscape is rolling to undulating, but in a wider sense, also rolling to hilly areas are present.

These surfaces are at heights between 400 - 700 m. The weathering mantle is very shallow in the cuestas themselves, but it is accumulated as erosion products on the lower part of the slopes and in the valleys. Limestone rock outcrops are common in the higher parts of the cuestas. The limestone strata is the hardest rock of the area and they are on top of the other materials protecting them against erosion. The steepness of the cuesta - as usual - decreases when it goes from the anticline nucli to the SE and after 15-20 km the beds become almost horizontal. Two general remarks seem necessary: in some areas the general trend of the cuestas is marked by faults and in others some buttes testify the existence of older cuesta levels.

The drainage is through two main permanent streams: the Sio River and the Llobregos River. The former flows in the south and the latter in the north through the anticline core. The small tributaries carry water only after the storms. The lowest part of the cuesta consists in many cases on dry minor valleys, where no stream exists and where only in the very large storms water flows through. Calvet and Gallart (1979) concluded that the valleys and drainage system is inherited from past geological times.

Several wells exist - some of them at 800 m from profile E-19 - but they only supply small amounts of water.

1.2.4 Vegetation and land use

The area has been subjected to cultivation for a very long period of time. According to Bolos (1958) the climax vegetation is Violo-Quercetum valentinae alliance Quercion pubescenti - petraedae with oak (Quercus faginea subsp. valentina) being the dominant tree at heights above 600 m, below that Quercetum rotundifoliae alliance Quercion ilicis is the climax with holm-oak (Quercus ilex subsp. rotundifolia) as the main tree. When the vegetation is removed the maquis developes with Quercus coccifera as a main bush. The oak can be found also at heights well below 600 m, on the N and W facing slopes. Only on the shallowest soils or on the steepest slopes forest existed until recent years (two or three decades ago), but now it is under rapid regression and the land is been used for cereals.

The agriculture was of Mediterranean type, with olives, vineyards and winter cereals (barley and wheat). Now, the social changes, the use of heavy machinery and the market prices have put almost all the area under winter or spring cereals cultivation.

It is difficult to trace back the beginning of the human activity on these soils. Guisona, the main population of the area, was founded by the Romans, (II-III century B.C.). Also the network of populations was already existing in the XII century, but with a very low population density. It stayed more or less constant until the beginning of the XVIII century. The intensity of the deforestation and the agricultural use of the land has been increasing from that date until the present time.

2. SITE AND SOIL

2.1 Site characteristics

The soil profile E-19 is located in a E-W, 400 m wide, slightly concave bottom of a minor valley, in the cuesta areas. The approximate coordinates are 41°44'20" N, 1°22'10" E and 650 m height above sea level. The site is flat or almost flat and it has a man made meso-relief consisting of stone walls 1 to 2 m high, at distances of 300-600 m and constructed perpendicular to the slope of the valley. No water course is present in the valley. No stones or rock outcrops are in the land, and only a few limestone gravels are on the ploughed surface.

The soil profile E-20 is located 1500 m SW from profile E-19 in the back front cuesta. The coordinates are 41°43'30" N, 1°21'40" E and the height is 700 m above sea level. The site is flat to undulating and there is some mesorelief owing to man made stone walls, less than 1 m and 300-500 m apart. There are no stones or rock outcrops, but deep subsoiling has brought to the surface stone and gravel size calcrete.

Both sites have been dedicated to agriculture for a long period of time, and at the present moment winter cereal is the landuse. The soil is cropped from October to July and bare in September. The groundwater table is several meters deep and has no influence in the soil. Run-off occurs at site E-20, but only sheet- and rill erosion develops. On site E-19 run-on accumulates, and water is ponded for a short time (up to one or two days) after a summer- or autumn rain storm.

Profile E-20 is developed in situ from siltstones, marls and limestones; profile E-19 is developed in short transported colluvial materials accumulated in the foot slopes and valleys, process enhanced by man.

The climate according to Köppen is: Mild humid climate, with a dry, hot summer (Csa), with a mean monthly temperature of 13°C, a mean monthly temperature of the hottest month of 23.8°C and a mean monthly temperature of 4.0°C for the coldest month. The mean annual rainfall is 530 mm with 98 mm for the three coldest months (December, January, February) and 104 mm for the hottest months (June, July and August); the precipitation is somewhat larger in spring and autumn but the interannual variation is very important (231-760 mm, table 2). The PE largely exceeds precipitation and only from October to April it is below or similar. That gives a shortage of water and so the summer is very dry.
A detailed sites description is given in Appendix I, Soil Data.

2.2 Brief description of the soils

Profile E-19
The soil profile E-19 is a deep, medium textured, well drained soil. The horizon differentiation is made on basis of the structure, $CaCO_3$ accumulation and gravel content. The soil pH is high (pH water > 8). Calcium carbonate accumulations are present in the form of pseudomycelia in the Bwt horizon and as a generalized accumulation in the lower parts of the soil. Gravel content is below 8% in the first 105 cm, and then increases up to 69%.

The top soil (Ap horizon) has a wavy boundary between 26-30 cm and it consists of a dark brown loam, with a faint content of organic carbon (i.e. 1.1%). Structure is granular and the lower part of the horizon is somewhat more compact.

The Bwtl horizon is a dark brown to light brown loam changing gradually with depth to clay loam. The structure is strong coarse subangular blocky parting to very strong coarse granular. The $CaCO_3$ accumulation is in the form of pseudomycelia, but the content of carbonates is rather low (i.e. less than 10%). Micromorphological studies reveal the presence of few argillans. The lowest part of the horizon (i.e. at 97 cm) shows a higher degree of $CaCO_3$ accumulation in the form of micrite.

The Bwtl horizon changes at 105 cm, with an abrupt boundary, to a gravelly to very gravelly underlaying horizon of $CaCO_3$ accumulation.

Profile E-20
It is a moderately deep, medium textured, well drained soil. The horizonation is made on basis of $CaCO_3$ accumulation and structure. It has been deeply subsoiled up to 52 cm and fragments of the underlaying horizons have been brought to the Ap and Bw horizons. The pH is high (i.e. 8.3) and the organic matter content is fair. The calcium carbonate accumulation is strongly cemented after 52 cm.

The topsoil (Ap horizon) is a 25 cm deep, ploughed horizon, and it consists of a dark brown to light brown silty loam, with a fair organic matter content (i.e. 1.26% organic carbon). Structure is weak granular. Gravel sized fragments from the underlaying calcrete are present. The carbonate content is high.

It merges with a wavy boundary into a Bw horizon with a weak, fine, subangular blocky structure. The calcium carbonate content is very high. It extends to a depth of 39 cm.

The Bwl horizon changes to an accumulation of secondary $CaCO_3$ (i.e. more than 90% equivalent $CaCO_3$), weakly cemented in the beginning (up to 52 cm), but later the cementation becomes strong.

Reference is made to Appendix I for a detailed description of the profiles, their micromorphology and analytical information.

2.3 Soil pattern

The soil pattern of the sites part of La Segarra is described (Figure 6) using information from Porta et al. (1981), Herrero (1985) and the author's field work. The soils can be divided in:

A. Soils derived from calcareous parent material (marl, limestone, siltstone) and their colluvium/alluvium.

The soils of the structural platforms and the back slope cuesta are developed in situ, with some colluvial gains in the footslopes. They are shallow and are classified as a function of soil development and/or depth to a lithic contact in a hard, somewhat cracked limestone, which shows hard coatings of lime. They are low in organic matter, but it is a common fact that the shallowest ones have the highest organic matter content, because they have been under forest up to now. The shallow soils are also stony because their plough has brought to the surface some of the thinner limestone strata. They are Calcaric Regosols (Lithic and Typic Xerorthent) the main, but when soil development has been higher Calcic Cambisols (Calcixerollic and Typic Xerochrepts) are present. A few places have soils with a petrocalcic horizon at depths not larger than 50 cm, being Calcic Cambisols (Petrocalcic Xerochrepts). Because the parent material contains already some salts it has been described, mainly in the lowest structural platform, soils with some salts in the profile, Calcic Cambisols (Typic Calciorthids).

The steep sides of the structural platforms have soils with man-made terraces and they are mostly Calcaric Regosols (Typic Xerorthents). When a more stable surface is present, Calcic Cambisols (Calcixerollic Xerochrept) can be found.

The minor valleys have soils developed in colluvium/alluvium coming from the adjacent slopes. They are deep, well drained, almost free of stones in valleys with very different widths and almost always flat. They have a deep calcic horizon or soft powdery lime and a fluventic character. The classification is Calcic Cambisols (Calcixerollic Xerochrept).

The narrow alluvial valley of the Sio River has soils which are in fact very similar to the ones of the minor valleys, that is Calcic Cambisols (Calcixerollic Xerochrept). However, some inclusions of Calcaric Fluvisols (Typic Xerofluvent) are also present.

The cuesta front scarp consists of several drops with steep slopes, N oriented and narrow, elongated valleys among them, which run parallel to the cuesta scarp. The soil pattern is very complex and similar soils can be found in positions alike the described before. The area is terraced in many small, elongated fields. The dominant soil is Calcaric Regosol (Typic Xerorthent with inclusions of Lithic Xerorthent and Typic Torriorthent), but more stable positions have Calcic Cambisols (Calcixerollic, Petrocalcic and Typic Xerochrept).

B. Soils derived from gypsiferous parent materials and their colluvium/ alluvium

The eroded hills are an almost bare surface, with sparce natural vegetation. The soils are very shallow and show features as gypsum crusts or powdery gypsum. The content in calcium sulphate is very high and they are poor in organic matter. Their classification is Calcaric Regosols (Typic Torriorthent).

Several terraced and cultivated minor valleys occur between the hills. They are filled up with the fine textured colluvial/alluvial materials that are gypsum rich. They are Calcic Cambisols which commonly have a gypsic horizon (Typic and Cambic Gypsiorthids) but some more stable positions have in addition a calcic horizon (Calcic Gypsiorthids) or even only a calcic horizon (Xerollic Calciorthids).

The Llobregos river, which drains the hilly area, but also the front scarp cuesta area, has in its alluvial valley Calcic Cambisols (Cambic Gypsiorthids). Minor areas of Calcaric Fluvisols (Typic Xerofluvents) are also present.

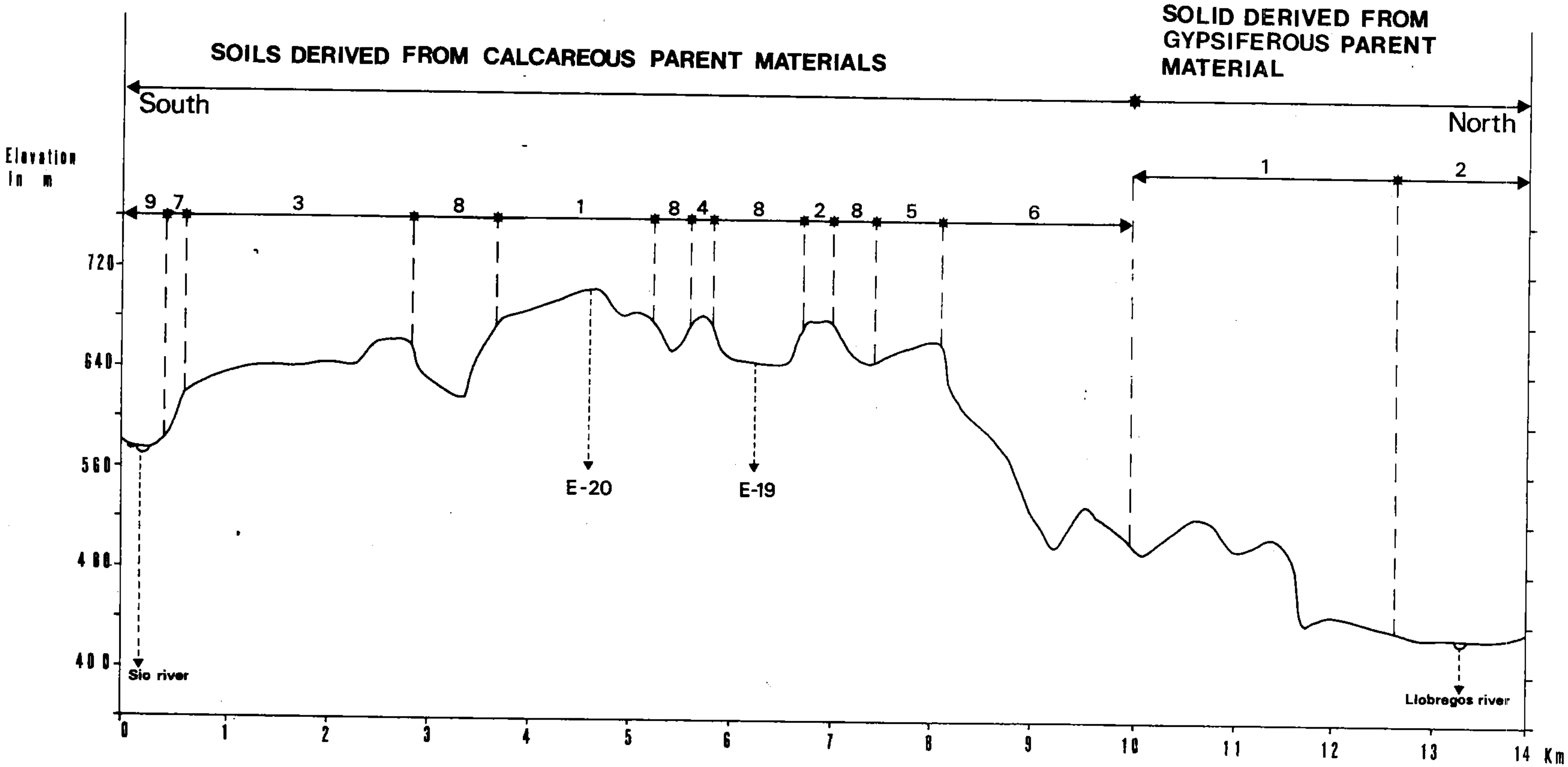


FIGURE 6. Soil pattern in the part of La Segarra, where the sites of profiles E-19 and E-20 are located.(Constructed with information from : Porta et al 1983, Herrero, J. 1985 and author's field work).

Legend of Figure 6

A. Soils derived from calcareous parent materials (marl, limestone, silt) and their colluvium/alluvium.
   1. Soils of the main structural platform.
      Calcaric Regosols (Lithic Xerorthent) with inclusions of Calcic Cambisols (Petrocalcic Xerochrept).
   2. Soils of the first structural platform.
      Calcic Cambisols (Petrocalcic Xerochrept and Calcixerollic Xerochrept) with inclusions of Calcaric Regosols (Lithic Xerorthents).
   3. Soils of the lowest structural platform.
      Calcaric Regosols (Typic and Lithic Xerorthent) with inclusions of Calcic Cambisols (Calcixerollic and Typic Xerochrept and Typic Calciorthids).
   4. Soils of the residual structural platform.
      Calcaric Regosols (Typic and Lithic Xerorthent)
   5. Soils of the back cuesta slope.
      Calcic Cambisols (Calcixerollic and Typic Xerochrept)
   6. Soils of the cuesta front.
      Calcaric Regosols (Typic Xerorthents, Typic Torriorthents and Lithic Xerorthents) with inclusions of Calcic Cambisols (Typic, Calcixerollic and Petrocalcic Xerochrept).
   7. Soils on the steep side slope of the alluvial valley.
      Calcaric Regosol (Typic Xerorthent) with inclusions of Calcic Cambisols (Typic and Calcixerollic Xerochrept).
   8. Soils of minor valleys, including the connecting slopes up to the cuesta or structural platforms.
      Calcic Cambisol (Calcixerollic Xerochrept) and inclusions of Calcaric Regosols (Typic Xerorthents).
   9. Soils of the alluvial valley.
      Calcic Cambisols (Calcixerollic Xerochrept) with inclusions of Calcaric Fluvisols (Typic Xerofluvents).

B. Soils derived from gypsiferous parent material and their colluvium/ alluvium.
   1. Soils of the hilly area.
      1.1 Soils of the eroded hills.
          Calcaric Regosols (Typic Torriorthents).
      1.2 Soils of the minor valleys, derived from colluvium.
          Calcic Cambisols (Typic Gypsiorthids and Cambic Gypsiorthids with inclusions of Calcic Gypsiorthids and Xerollic Calciorthids)
   2. Soils of the alluvial valley.
      Calcic Cambisols (Cambic Gypsiorthids) with inclusions of Calcaric Fluvisols (Typic Xerofluvents).

3. SOIL GENESIS

3.1 Soil forming processes and factors

The soil forming processes operating on these soils are mainly the redistribution of carbonates, the incorporation of organic matter, clay illuviation and biological mixing. Because parent material plays a major role in the development of those processes a word must be reserved to it. Although human action bears some influence in profile E-19, the profile E-20 can only be interpreted taking into account such action as a predominating factor.

3.1.1 Parent material

Pedon E-19
The parent material is not homogeneous, at least at the level of particle size distribution. In the first 105 cm the heterogenity of the material is pointed out by the distribution of hard limestone gravels (fig. 7); the disposition of the large fragments, more or less at random (Appendix I), and without any special orientation, shows that the parent material is a calcareous colluvium from the surrounding slopes. The lower part of the soil mostly consists in several limestone gravel layers and it most be assumed that they were transportated under another environmental conditions than the ones dominant during the depositions of the top part of the profile; the climate had to be more aggressive and with higher erosion capacity. All the aforementioned materials overlie a horizontal, cracked, hard limestone strata more than 20 cm thick.

Pedon E-20
The position of the profile on top of the slope must lead to the conclusion that the soil is developed chiefly from the Tertiary sedimentary siltstone, marl and limestone. At the present, the soil is underlaid by a hard limestone strata, similar to the one of profile E-19.

3.2 Relevant soil forming processes

The presence of a solid phase carbonate in the soil stabilizes the concentration of relevant cations in the soil solution (Novozamsky and Beek, 1978). Active carbonate (particles smaller than 50 µm) is a curb on the process of weathering, little iron being freed (Duchafour, 1982).

The $CaCO_3$ - H_2O - CO_2 system is then of major importance in the soil forming processes in calcareous parent materials, the redistribution of $CaCO_3$ being one of the first operating ones. Several aspects of that system, its behaviour, and relationships must be considered in order to interpret the genesis of these soils.

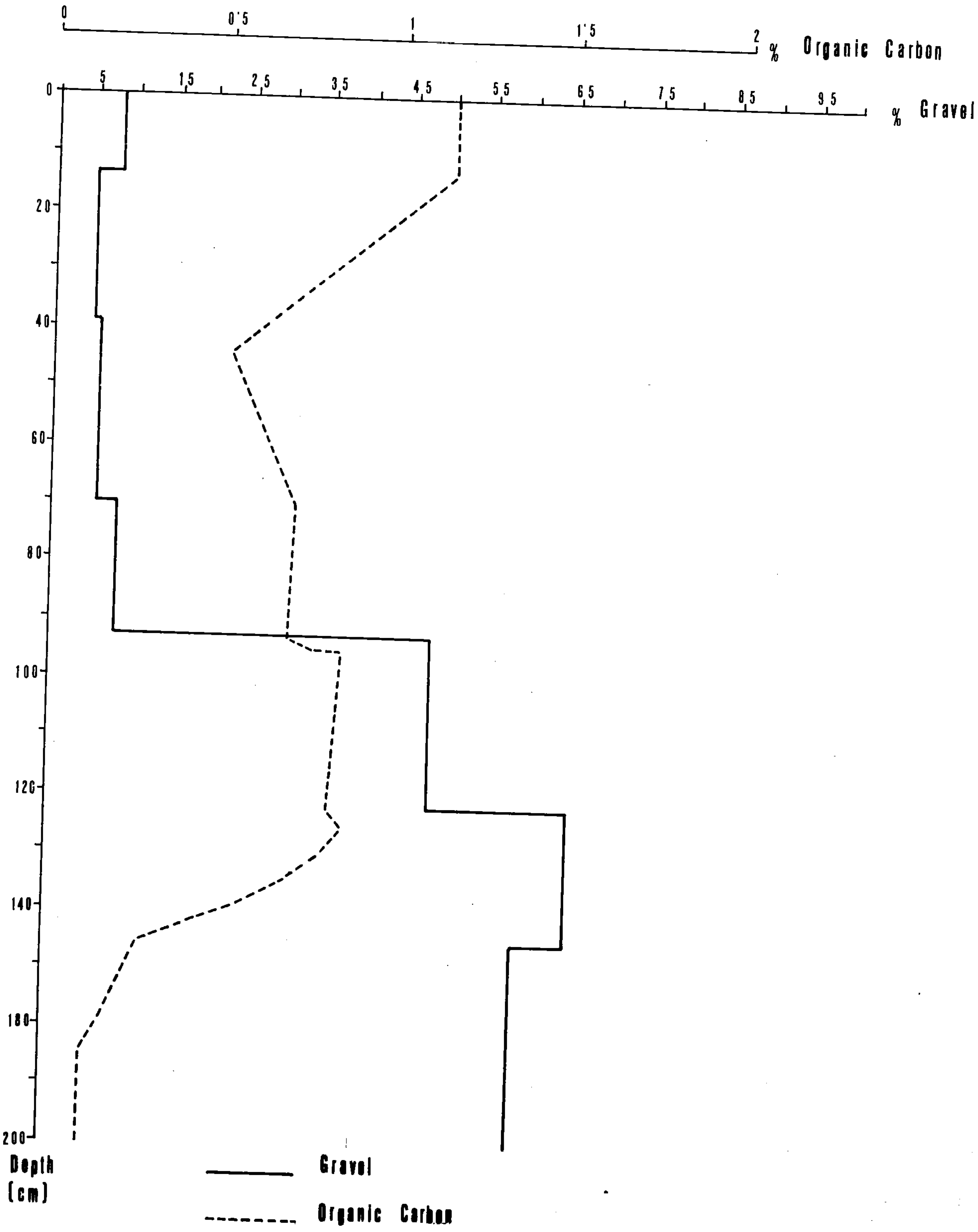


FIGURE 7. Contents of gravel and organic carbon profile E-19

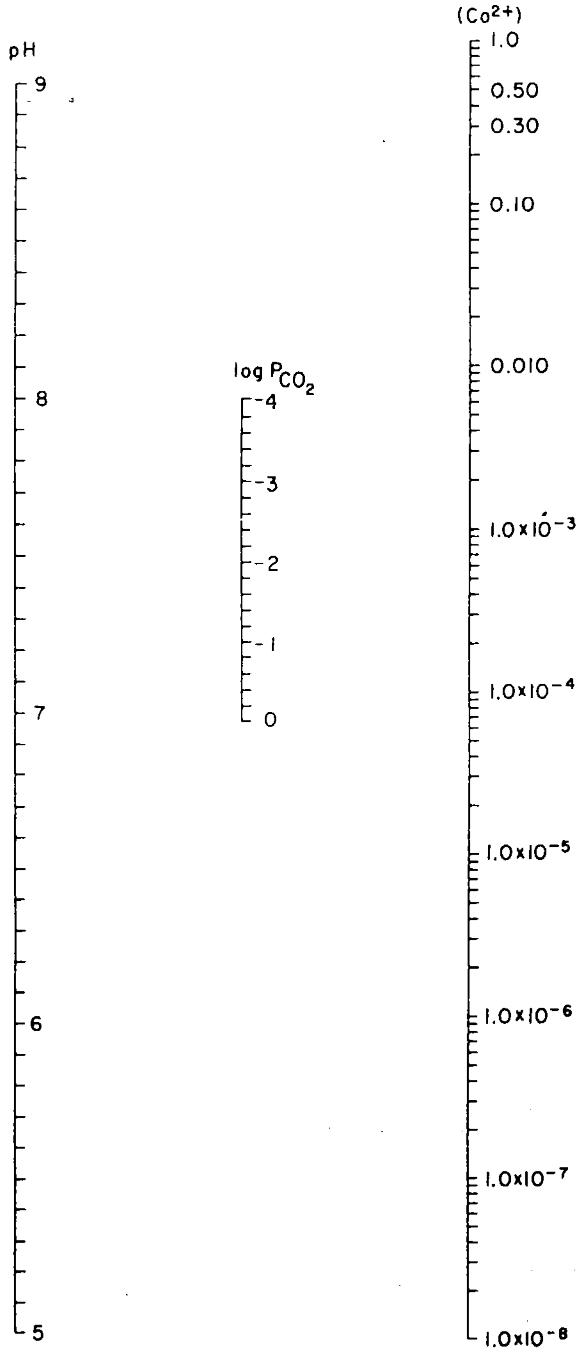


Fig. 8 An alignment chart relating pH, P_{CO_2}, and Ca^{2+} activity (concentration) for calcite from the equation: 2 pH + log P_{CO_2} = 9.76 + log $[1/(Ca^{2+})]$.
(After Doner and Lynn, 1977)

TABLE 3. Equilibrium of $CaCO_3$ and pH at Various CO_2 Pressures of Air at 25°C. (From Jenny, 1980).

CO_2 content of air: Volume (%)	CO_2 content of air: Atmosphere P	$CaCO_3$ dissolved (mg/l H_2O) Kline	pH of Ca-bicarbonate solution[a]	Environmental conditions
0.031[b]	0.00031	52	8.35	Average CO_2 content of air
0.334	0.00334	117	7.68	Average CO_2 content of soil air
1.60	0.0160	201	7.24	
11.16	0.1116	403	6.70	High CO_2 content of soil air
100	1.000	900	6.10	Water saturated with CO_2 at 1 atm pressure

[a] From eq. (2) and column 3 after conversion to activities and using Kline's (1967) ionic strengths.

[b] Or 310 ppm.

3.2.1 Dissolution of soil carbonates

The reaction describing the dissolution of $CaCO_3$ can be written as:

$$Ca^{2+}(aq) + 2H^{+}(aq) \rightarrow CaCO_3(s) + H_2O + CO_2(g) \quad (1)$$

and the equilibrium situation according:

$$2pH + \log P_{CO_2} = 9.76 + \log [1/Ca^{2+}] \quad (2)$$

Equation (2) is used to draw figure 8, from Donner and Lynn (1977). It can be seen that in the solubility of $CaCO_3$, the CO_2 partial pressure plays a major role.

The content of CO_2 in the soil increases with organic matter and biological activity, especially root activity. CO_2 concentration usually also increases with depth (Koorevar et al. 1983); if steady state is the situation it reaches a maximum at the bottom of the root zone, and from that down it remains constant.

At the atmosphere the content of CO_2 is almost constant, but in the soil that value can be much higher. Table 3 from Jenny (1980) shows several values of CO_2 content in soils and the amounts of dissolved $CaCO_3$ using equation (2).

The pH of profiles E-19 and E-20 is high (always higher than 7.9 in 1/2.5 water), but it is pointed out (Crahet, 1967) that the soil in contact with the root has a more acid pH than the measured in the laboratory and it must

be expected to have a much higher solubility of $CaCO_3$ than when figure 8 is used. Table 3 also refers to pure calcite, but calcareous materials in several soils have been found more soluble than the calculated, assuming pure, well crystalized calcite (Olson and Watanabe, 1959), suggesting that impurities present in the crystal lattice can explain it.
Another fact which also has a role in the solubility of $CaCO_3$ is the soil temperature, increasing when temperature decreases (Jenny, 1980).

3.2.2 Leaching and accumulation of $CaCO_3$

The dissolution of $CaCO_3$ comes when water enters the soil. Then the water moves down to the layers of high moisture, dissolving $CaCO_3$ and transporting it to lower parts of the profile, where the wetting front stops. Wieder and Yaalon (1974) stated that the precipitation of the soil solution in a calcic horizon was done in the form of small crystals (1-8 µm). The depth reached by every shower is different and they can give very complex profiles of $CaCO_3$ distribution; those depths reached by the wetting front in a certain area is also a function of the AWC of the soil (Appendix III) ; especially profile E-19 has a very low AWC (pF 2 - pF 4.2) which does not agree with the textural class found in the analytical determinations (Appendix III) and that will mean a deeper accumulation of $CaCO_3$ than expected.

The distribution of the rainfall also is important. Although the rain is rather evenly distributed in La Segarra, the summer rain will be not very profitable for leaching of $CaCO_3$ because the soil is too hot, too dry and wetting front can not go deep, but also the amount of $CaCO_3$ is very low in the percolating water. The wet years are very important in the leaching process and together with long term average depth of moisture penetration will control the depth of $CaCO_3$ accumulation. Run-off occurs in E-20 and run-on in E-19 and together with the AWC they create a different expectable depth of $CaCO_3$ accumulation. However in the present case that depth of accumulation is disturbed due to:

A. Profile E-19

a) Coarser textured materials underlying finer materials restrict the movement of water, especially under unsaturated flow (fig. 8). Stuart and Dixon (1977) suggest that in many cases the accumulation of $CaCO_3$ develops in the interface between both materials. That seems not to be the case in E-19, but the increases of micrite between 82 and 103 cm must be attributed to that phenomenon.

b) The accumulation of $CaCO_3$, when recalculated on a total soil weight basis (> 2 mm + gravel) shows two maxima (fig. 10 and Appendix I). One explanation could be the existence of two different sedimentation phases.

c) The maximum depth of $CaCO_3$ accumulation was restricted by the limestone strata. More than 200 mm water is necessary to reach that depth now and with the present climatic conditions they do not seem available. The flow of water through the limestone is restricted to the cracks, which can be attributed to tectonics, and they are widely separated, the flow in unsaturated conditions being very low, but higher under saturation. The water flowing in the cracks, now hardly can be expected to dissolve the limestone because it is oversaturated with Ca; however, hard coatings of lime are present below and in the cracks.

B. Profile E-20

The effect of the limestone strata in profile E-20 is similar to that discussed for profile E-19, but at the present time the restriction in the water flow is made by the cemented $CaCO_3$ accumulation.

3.2.3 Accumulation forms of carbonate

A. Profile E-19

The accumulations observed in the field are only of two types: pseudomycelia and generalized accumulation. The pseudomycelia are composed, almost completely, of lublinite crystals, which grow in voids when water is evapotranspirated. Wieder and Yaalon (1974) attributed these long acicular crystals to be the first stage in the precipitation of $CaCO_3$. It seems to be also the case now, but it must be stressed that in the two top horizons their life is ephemeral. The pseudomycelium is not evenly distributed, being more abundant in certain layers; that points out the fact that when the soil is remoistened, the pseudomycelia dissolve again and disappear. The presence of lublinite is also a good indicator of the xeromorphic character of the soil (Baal and Buursink 1976), where the moisture for leaching is available a few times. The presence of lublinite also shows that the lime is authigenic and the process is going on at this very moment, because it is precipitated in voids and the acicular crystals can not survive transport.

The generalized accumulation shows to be micrite crystals. That is in good agreement with the observation of Wieder and Yaalon (1982) that increases in carbonate segregation is associated with increases in micrite. The presence of lublinite and the disposition mainly as a pendant of the micrite, stresses the authigenic origin of that $CaCO_3$. The cementation of the horizon is due to the fact that when the soil becomes engulfed in micrite, and some cementation starts, then percolation is somewhat restricted and the accumulation grows upwards.

The micrite is present in appreciable quantity only below 105 cm. Its content increases downwards from the topsoil, and at 97 cm it develops accumulations according to micromorphological observations. However, the increase in the $CaCO_3$ is only noticable by chemical analysis, or in the field, below 105 cm.

Large single $CaCO_3$ crystals are usually associated with direct precipitation. Their number increases from the topsoil up to 105 cm, embedded in the groundmass and randomly distributed. Their presence can be explained in a combination of two different ways:

- they are inherited from the parent material,
- they are developed in large voids and later, by fauna activity, incorporated into the groundmass of the soil.

According to the stages of K horizon development proposed by Gile et al. (1965) that horizon would correspond with a stage III in a gravelly material.

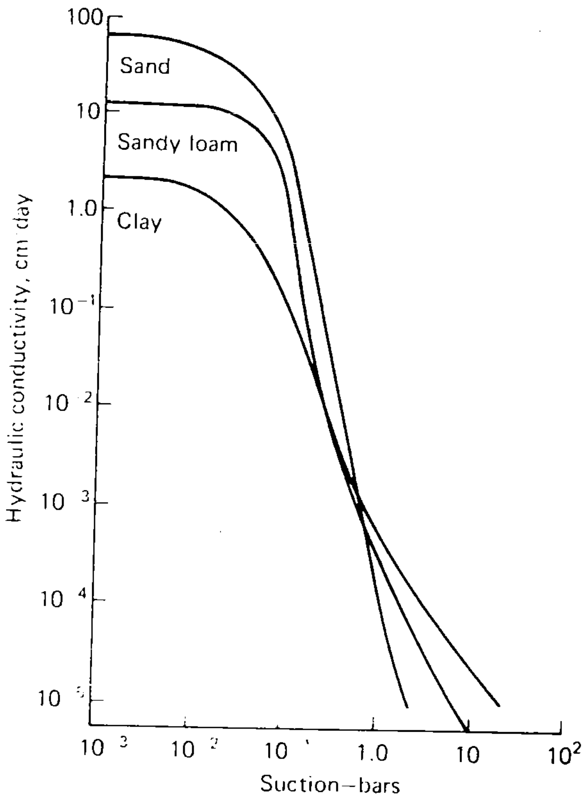


Fig. 9. Values of conductivity K for a sand, a sandy loam, and a clay at increasing suctions. Near the vertical axis the soils are water saturated; to the right they become increasingly dry (graph from U.S. Salinity Laboratory)

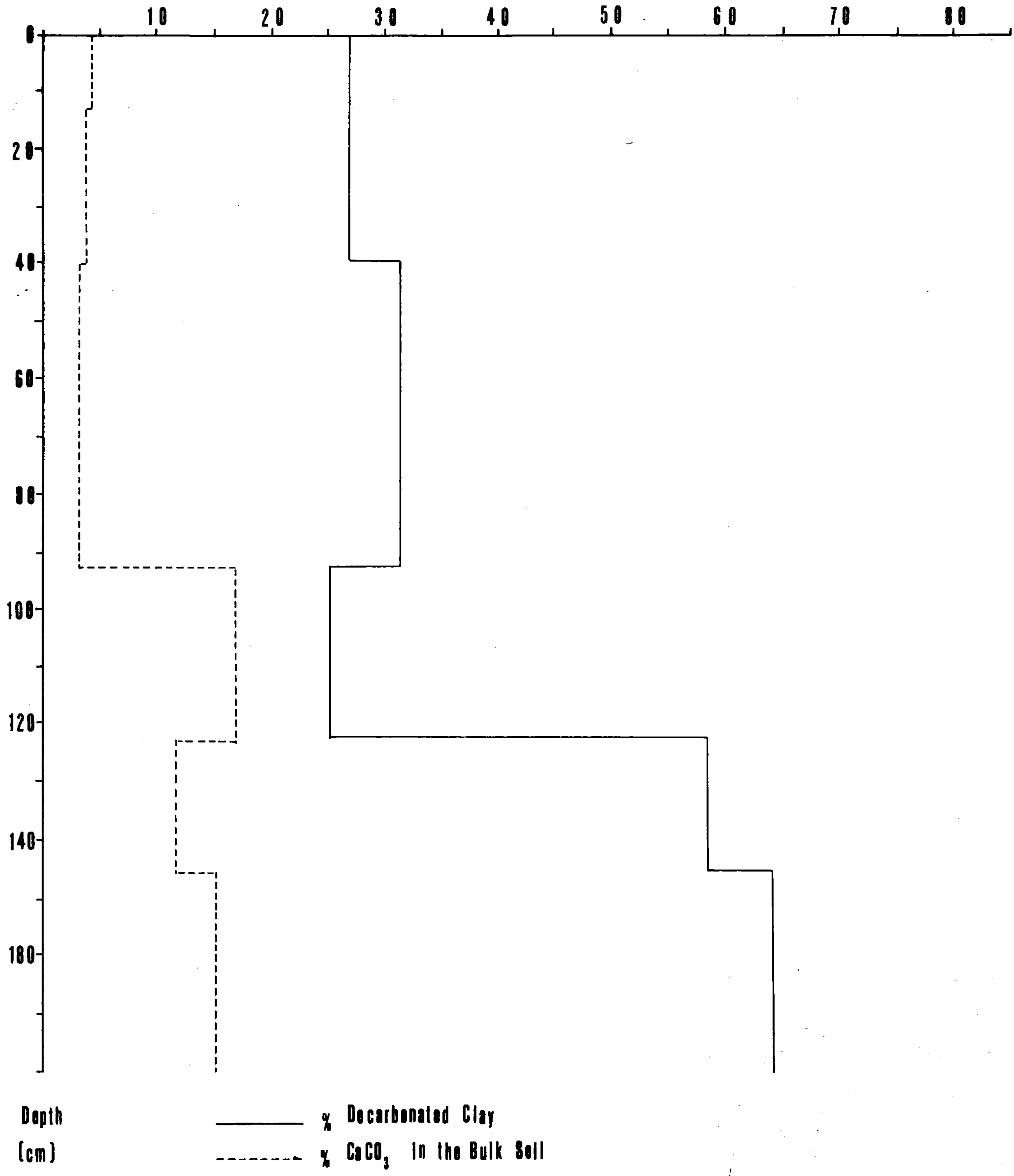


FIGURE 10. Non-carbonatic clay content (%) and CaCO (%) in the bulk soil (E-19)

B. Profile E-20
That profile has a massive accumulation of $CaCO_3$ as from 39 cm depth overlain by a horizon where accumulation occurs in the form of nodules.

The soil has been subsoiled to a depth of 52 cm and the materials are disturbed. The top part of a petrocalcic horizon (stage IV in non-gravelly materials according to Gile et al., 1965) was brought to the surface and later on removed by man, only small fragments remaining now.

The significance of the different micromorphological features is similar to those discussed before. The presence of nodules must be interpreted as a more advanced stage of micrite accumulation (Wieder and Yaalon, 1982). The continuously cemented horizon consists of several subhorizons, described by Ruellan (1973) as a "croute calcaire" and it develops when all the subhorizons become plugged, engulfed and cemented by $CaCO_3$.

Concerning the amount of $CaCO_3$ accumulated in the soil it is necessary to point out that no calcareous material - except the hard, pure limestone - is known to exist in La Segarra able to give such amount of $CaCO_3$ when it weathers with as few residues. The explanation can be:
1. The soil is derived from pure limestone.
2. An external source of $CaCO_3$ existed.
3. Erosion has taken place.

Observations made in the surrounding area where only very shallow soils are present and the fact that some carbonate nodules have an outer layer which is relatively richer in clay and quartz grains, seems to make the last hypothesis of an old, eroded soil the most likely one.

3.2.4 Clay migration

Although not observed in the field, the micromorphological study (Appendix I) has shown the existence of very thin argillic coatings in voids of the Bwt1 horizon and around coarse grains in the Ap horizon of profile E-19. The same micromorphological study reveals that no decalcified zones are present.

It is usually assumed that clay migration only occurs if the exchange sites of clay have been partially desaturated, but Mohr et al. (1972) stated a possible explanation for clay migration in calcareous materials. It consists in that a soil in a dry period, with almost no biological activity in the topsoil and with cracks which allow free flowing of water, when a heavy rain occurs, there is no equilibrium between the solid calcite and the solution. The partial pressure is not raised. The pH of the soil surface will be very high. The effect of the temporarily high pH values is that the surface potential of the clay particles increases by the fact that > SiOH and > AlOH groups of the clay particles dissociate, as the dissociation constants of the hydroxils vary between 10^{-8} and 10^{-16}. The results of the increased surface charge and low concentration of Ca^{2+} is that the possibility of defloculation and clay migration exists.

The conditions suggested by Mohr et al. (1972) are present in E-19 from July to September, when heavy rains falling on a dry soil, with some cracks, are common. In addition the soil is bare, without vegetation, after the harvesting.

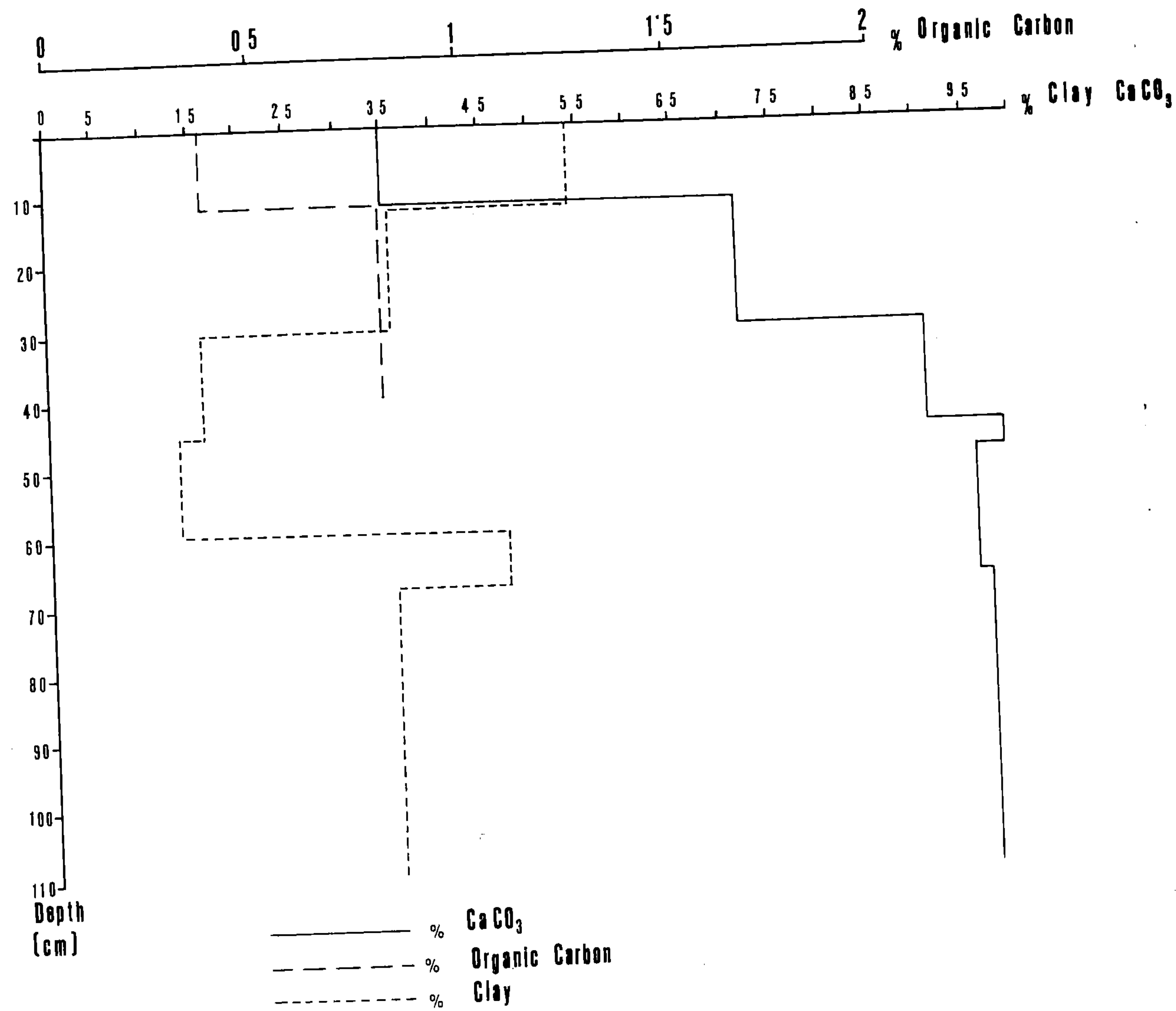


FIGURE 11. Distribution (%) with depth of organic carbon, clay and CaCO in profile E-20

Although the horizon Bwtl shows an increase of silicate clay at depths of 90-105 cm the number of coatings observed are not sufficient to explain the increase of clay solely due to the process of clay migration. Because clay coatings are the only form of illuviation found it must be assumed that the larger amount of clay in the lower part is due to some neoformation and/or differences in the clay content of the parent material.

3.2.5 Humification

A. Profile E-19

The irregular distribution of organic carbon (fig. 7) must be due to the combination of the three following facts:

- The pattern of distribution is inherited from the parent materials.
- The high calcium carbonate content curbs the evolution of organic matter.
- The soil fauna activity is not extremely high.

B. Profile E-20

The incorporation of organic matter with depth is done mainly through the plant roots. Because the calcium carbonate content is extremely high the evolution of humus is blocked in the early stages and it accumulates especially in the areas where roots are searching for water in the calcareous crust.

3.2.6 Biological mixing

Both soils have a very active biological mixing in the topsoil. The Bwtl horizon of the profile E-19 shows many aggregates (Appendix I) which seems to be related to fauna. However, the biological mixing does not show to be very active in the turn-over of the profile E-19, because the pattern of sedimentation due to colluviation is still reflected by the irregular organic matter distribution in the profile. That apparent contradiction can be explained if the results of the faunal activity are preserved, like Eswaran et al. (1981) stated for Aridisols and few other soils.

4. SOIL CLASSIFICATION

4.1 FAO-UNESCO, Soil Map of the World Legend

A. Profile E-19
Diagnostic horizons

The mineral Ap horizon has a base saturation of 100%, an organic matter content higher than 1% (i.e. 1.5%), a thickness of more than 25 cm (i.e. 26 cm) and a structure strong enough to qualify it as a mollic A epipedon. However, the chroma and the moist value are too high (i.e. 4/4) and therefore it must be considered as an ochric A horizon.

The Bwtl and the 2Bwk2 horizon meet the following requirements of a cambic B horizon:
- their textures are loam and clay loam. Hence, much finer than loamy very fine sand;
- they have soil structure throughout;
- the cation exchange capacity is much larger than 16 meq/100 g clay (i.e. about 46 meq/100 g clay by the NH_4OAc method);
- the base of the Bwtl is at a depth of 105 cm and the base of the 2Bwk2 at a depth of 104 cm, that is much more than 25 cm;
- the Bwtl has evidence of redistribution of carbonates and the underlying horizon has much more calcium carbonate. In addition the horizon 2Bwk2 has all the coarse fragments coated with lime, but Bwtl has the coarse fragments free of coatings.

From the points aforementioned it must be concluded that the cambic B horizon extends to a depth of 105 cm, that is, the Bwtl horizon.

The horizons 2Bwk2, 3Ckl and 4Ck2 are more than 15 cm thick (i.e. 75 cm) and have more than 15% of $CaCO_3$ (i.e. from 23% to 32%). Because they are overlying a limestone rock (> 40%$CaCO_3$) the percentage of calcium carbonate does not need to decrease with depth. From the presence and amount of the mentioned secondary carbonate enrichment that set of subhorizons forms a calcic horizon.

Other diagnostic soil characteristics

From Appendix III it appears that the soil moisture control section is moist in some parts more than 90 consecutive days while the soil temperature at 50 cm is continuously above 8°C. In most years the moisture control section is moist more than half of the time (cumulative) that the soil temperature at 50 cm is above 5°C and also in most years the moisture control section is moist in all parts for as long as 60 consecutive days during 3 months following winter solistice. It is inferred also from Appendix III, that mean annual temperature is less than 22°C (i.e. 14°C) and mean summer and mean winter temperatures differ more than 5°C (i.e. 15°C). It must be concluded that the soil has not an aridic moisture regime.

The field description (Appendix I) mentiones strong reaction with HCl throughout the soil. Then, the soil must be considered calcareous (Soil Survey Staff, 1975).

The weighted average textural class of soil E-19 is medium (Appendix I).

Classification

From the above it appears that the soil has an ochric A horizon, a cambic B horizon and it lacks an aridic moisture regime. With this set of characteristics the soil keys out in the main unit Cambisols of the FAO-UNESCO Soil Map of the World Legend.

In addition to this the soil has a calcic horizon starting at 105 cm and a weighted textural class medium. In agreement with that the soil can not be placed in the Calcic Cambisols, because with its textural class the calcic horizon must be within a depth of 90 cm to be diagnostic. Following the key the soil must be placed in the Eutric Cambisols. However, the definition of the soil units (FAO-UNESCO, 1974) states: "Eutric Cambisols: Cambisols having a ochric A horizon and a base saturation (by NH_4OAc) of 50% or more at least between 20 and 50 cm from the surface but which are not calcareous within this depth...". The micromorphological study (Appendix I) reveals a presence of $CaCO_3$ right from the surface; nevertheless such concentrations do not qualify as soft powdery lime because the surface covered is very little. However taking into account the genesis and characteristics of this soil, the best suited unit of the FAO-UNESCO legend seems to be Calcic Cambisol. The discrepancy may be explained by the very low water holding capacity in the topsoil of profile E-19, more alike to a coarse sandy loam (coarse texture) than to a medium textured soil. In the case of coarse textures the upper limit of a calcic horizon must be within 125 cm from the surface. It should be pointed out that this problem is not specific of this particular profile, but seems to occur often in the region (personal observation).

B. Profile E-20
Diagnostic horizons

Similar to the Ap horizon of profile E-19, the mineral Ap horizon of profile E-20 meets all the requirements of a mollic A epipedon, except the colour. In the present case it is only the chroma (i.e. 4) that is too high when moist. It conforms therefore also an ochric A horizon.

The Bw has a texture finer than loamy very fine sand (i.e. clay loam), soil structure throughout, siginificant amount of weatherable minerals (i.e. CEC of about 36 meq/100 g clay, estimated by the Bascomp method), it is thicker than 25 cm (i.e. 39 cm) and has evidence of removal of carbonates, becuase it overlies a petrocalcic horizon. All these characteristics qualifies the Bw horizon as cambic B horizon (not withstanding its high lime content: 70%!).

The Cmk1, Cmk2, Cmk3 and Cmk4 horizons have an accumulation of secondary carbonates, are more than 15 cm thick (i.e. 36 cm) and they contain more than 15% of equivalent $CaCO_3$ (i.e. from 91 to 97%). The amount of $CaCO_3$ does not need to decrease becuase they rest on a limestone (more than 40% equivalent $CaCO_3$). Therefore they conform a calcic horizon.

Other diagnostic soil characteristics

Similar to soil E-19 the present profile does not have an aridic moisture regime (Appendix III).
The weighted average textural class is medium.

Classification

From the above it is apparent that the soil has an ochric A horizon, a cambic B horizon and a calcic horizon. It keys out into the Cambisols (FAO-UNESCO, 1974). Because the upper boundary of the calcic horizon is present at a depth of 39 cm it streightforwardly keys out as a Calcic Cambisol.

4.2 USDA Soil Taxonomy

A. Profile E-19
Diagnostic horizons

The mineral Ap horizon is not both massive and hard or very hard when dry, the base saturation by the NH_4OAc is higher than 50% (i.e. 100%), it has more than 0.6% organic carbon (i.e. 1.1%), it is thicker than 25 cm (i.e. 26 cm), and some part of the horizon is moist more than 3 months (cumulative) (Appendix III). However, the moist value and chroma are too high (i.e. 4/4) and that excludes it from a mollic epipedon. Hence it fits into the definition of an ochric epipedon.

The Bwt1 horizon is a cambic horizon because:
- the texture in the fine earth is finer than loamy very fine sand (i.e. loamy and clay loam);
- the horizon has soil structure in all parts;
- there is evidence of removal of carbonates. Its content is much lower than the underlying horizon (i.e. from 8% to 33%). In addition it does not have coatings in the coarse fragments, those fragments being fully coated in the underlying ca horizon;
- it has some argillans and an increase in the clay content in the lower part of the B horizon, but it is not enough to meet the requirements of an argillic horizon. It does not meet either the requirements of a spodic horizon;
- it is not cemented in any part;
- the base of the Bwt1 horizon is at 105 cm, that is much deeper than 25 cm.

The 2Bwk2 horizon does not meet the requirements of a cambic horizon because:
- it has coatings in the coarse fragments, and more $CaCO_3$ than the overlying B horizon (fig. 7);
- it is somewhat cemented.

However, the 2Bwk2, 3Ck1 and 4Ck2 fulfil the requirements of a calcic horizon because:
- they have secondary enrichment of $CaCO_3$, with more than 15% $CaCO_3$ (i.e. 33.8% to 23%). Because they rest on limestone, the amount does not need to decrease with depth;
- the thickness is more than 15 cm (i.e. 75 cm);
- it is somewhat cemented, but the cementation is not strong enough to qualify as a petrocalcic horizon.

Other diagnostic soil characteristics

From appendix III it appears that:

- the mean annual soil temperature is 14°C and the difference between mean summer and winter temperature at a depth of 50 cm is 16°C. That qualifies the soil temperature regime as mesic.

- the soil moisture control section is:
    + dry in all parts for 45 or more consecutive days within the 4 months that follow the summer solstice in 6 or more years out of 10;
    + moist in all parts for 45 or more consecutive days within the 4 months that follow the winter solstice in 6 or more years out of 10;
    + moist in some part more than half the time, cumulative, that the soil temperature at a depth of 50 cm is higher than 5°C;
    + moist in some part for at least 90 consecutive days when the soil temperature at a depth of 50 cm is continuously higher than 8°C in 6 or more years out of 10.

  All the above qualifies the soil moisture regime as xeric.

The control section extends from 25 cm up to 100 cm, and its particle size class is coarse loamy.

The distribution of organic matter decreases irregularly with depth and in addition there is more than 0.2% organic carbon at 125 cm (i.e. 0.83%). That means a fluventic character.

Although the electrical conductivity of the saturated extract was not determined, the high content of $CaCO_3$ of the soil together with the low EC of the extract 1/2.5 (i.e. < 0.52 mS/cm) leads to the conclusion that the conductivity in the saturated extract must be lower than 2 mS/cm.

From the analysis and micromorphological observations (Appendix I) it seems that no mineral is present in amounts larger than 40%, except quartz or feldspars in the fraction 0.02 to 2 mm. That fits the definition of mixed mineralogy class for a coarse loamy particle size.

Classification

The lack of other horizons or diagnostic characteristics than a cambic horizon places the soil in the Inceptisols. At suborder level the ochric epipedon and the absence of other diagnostic properties classifies it as an Ochrept.

The soil is an Ochrept, with a xeric moisture regime. Therefore, at the great group level of classification the soil is a Xerochrept.

At subgroup level it has all the requirements of the central concept, except that it has a calcic horizon within 105 cm and the organic carbon does not decrease regularly and it is more than 0.2% at 125 cm depth. Soil Taxonomy (Soil Survey Staff, 1975) does not provide any Calcixerolllic - Fluventic subgroup and one of both must be selected. Smith (1982), discussing that problem, stated that soils must be grouped together according to their behaviour, rather than on their properties;

although the calcic horizon is very deep (i.e. 105 cm) the fluventic character of the soil has little weight in the behaviour of that soil for the relevant uses and in agreement with that the soil should be placed in the Calcixerollic subgroup. For the family level it was concluded already before that the particle size class is coarse-loamy, the mineralogy class mixed and the soil temperature regime mesic. Thus, the complete classification of profile E-19 is Calcixerollic Xerochrept, coarse-loamy, mixed, mesic.

B. Profile E-20
Diagnostic horizons

Like the Ap horizon of soil E-19 the mineral Ap horizon of soil E-20 meets all the requirements for a mollic epipedon, except its moist chroma, i.e. 4 (the P_2O_5 content has not been measured). Thus, it is an ochric epipedon.

The Bw horizon has:

- a loamy texture, that is finer than loamy very fine sand;
- significant amounts of weatherable minerals in the form of micas, smectite and feldspars in the fine fraction. In addition the CEC of clay is larger than 16 meq/100 g clay (i.e. 36 meq/100 g), but with the Bascomp method;
- it is overlying a horizon of accumulation of $CaCO_3$;
- it does not have any of the properties required for a spodic or argillic horizon;
- it is not cemented;
- its thickness is more than 25 cm (i.e. 39 cm).

All the aforementioned qualifies the Bw horizon as a cambic horizon.

The underlying Cmk1, Cmk2, Cmk3, Cmk4 have an amount of $CaCO_3$ larger than 15% (i.e. 91 to 97%), are more than 15 cm thick (i.e. 36 cm) and because they overlie a hard limestone there is no need to have a decrease with depth of the $CaCO_3$ content. In addition to that the horizon from 52 to 75 cm is cemented by $CaCO_3$ with a massive structure. Thus, it is a petrocalcic horizon.

Other diagnostic soil characteristics

The soil moisture regime and temperature regime are the same as in profile E-19, that is: a xeric moisture regime and a mesic temperature regime.

The control section for particle size class determination stands from 25 cm to 39 cm. The class is fine-loamy.

The EC of the saturated extract is not known, but from the extract 1/2.5 which is lower than 0.4 mS/cm and from the dominant presence of $CaCO_3$ it can be assumed that EC of saturated extract is lower than 2 mS/cm.

The analysis (Appendix I) shows that there are more than 40% by weight of carbonates (i.e. 72%) in the fraction < 2 mm. That classifies it as a carbonate mineralogy class.

Classification

Soil E-20 has a cambic horizon and a petrocalcic horizon within a meter from the surface. Because it lacks other diagnostic properties it is an Inceptisol.

At suborder and great group level, like E-19, the presence of an ochric horizon and a xeric moisture regime keys out the soil into the Xerochrepts.

It meets all the requirements of a Typic subgroup, but it has a petrocalcic horizon at a depth of 39 cm. That is an extragrade and the soil is therefore a Petrocalcic Xerochrept.

As regards family level it has been said before that the particle size class is fine-loamy, the mineralogy clas carbonatic and the soil temperature regime mesic. The full classification is therefore Petrocalcic Xerochrept, fine-loamy, carbonatic, mesic.

5. REFERENCES

Baal, L. and J. Buursink (1976). An inceptisol formed on the "Dart-i-Esan Top" plain in North Afghanistan. Fabric, mineral and trace element analysis. Neth.J.Agric.Sci. Vol.24, p.17-41.

Bolos, O. (1958). La vegetacio. In: Geografia de Catalunya. Aedos, Barcelona, p.235-266.

Calvet, J. and F. Gallart (1979). Las "brechas calcareas" del Pla d'Urgell; su repartición espacial e interpretación. In: Muñoz, J., T. Aleixandre and J. Gallardo (Eds) - Actas de la III Reunión Nacional. El Cuaternario en medios semiaridos. Zaragoza, 1977. CSIC, Madrid, p.117-121.

Calvet, J. and F. Gallart (1979). Dos irregularidades en el drenaje de un sector de la Depresión Central Catalana (Depresión del Ebro). Influencia de los factores tectónicos, litológicos y climáticos en su genesis y conservacion. In: Muñoz, J., T. Aleixandre and J. Gallardo (Eds) - Actas de la III Reunión Nacional. El Cuaternario en medios semiaridos. Zaragoza, 1977. CSIC, Madrid, p.109-115.

Crahet, M. (1967). Le pH des sols calcaires. Bulletin AFES, Vol. 4, p.17-34.

Danes, R., J. Herrero and J. Porta (1981). Morfologia y clasificacion de suelos. In: J. Porta et al. Los suelos de La Segarra. CPALL. Lleida.

Donner, H.E. and W.C. Lynn (1977). Carbonate, Halide, Sulfate and Sulfide Minerals. In: Dixon, J.B. and S.B. Weed (Eds) - Minerals in Soil Environments. Soil Sci.Soc. of Am. Madison, p.75-98.

Duchafour, P. (1982). Pedology (translated by T.R. Paton). George Allen and Unwin. London - Boston - Sydney, 448 pp.

Eswaran, H., M. Ilarvi and A. Osman (1981). Mineralogy and Micromorphology of Aridisols. In: ACSAD (Ed.) - Proceedings Third International Classification Workshop. Damascus, p.153-175.

FAO (1977a). Guidelines for Soil Profile Description. Rome, 64 pp.

FAO (1977b). Crop water requirements. FAO Irrigation and Drainage Paper 24. Rome, 144 pp.

FAO (1984). Extend and characteristics of the soil units of the Soil Map of the World in the developing countries (computer print out at ISRIC).

FAO-UNESCO, (1974). Soil Map of the World 1 : 5,000,000. Vol.I: Legend. Paris, 59 pp.

FAO-UNESCO (1971-1981). Soil Map of the World 1 : 5,000,000. Vol.II-X. UNESCO, Paris.

Gile, L.H., F.F. Peterson and R.R. Grosman (1966). Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Science Vol.101 (5) p.347-360.

Henero, J. (1985). Personal communication. Dep. Sols i Clima. ETSIA, Lleida.

Jenny, H. (1980). The soil resource Origin and Behaviour. Vol.37. Ecological Studies. Springer Verlag, Berlin. 378 pp.

Julia, R. and M.A. Marques (1981). Geologia de La Segarra. In:J. Porta et al. Los Suelos de La Segarra. CPALL, Lleida.

Koorevar, P., G. Menelik and C. Dirksen (1983). Elements of Soil Physics. Vol.13: Development in Soil Science. Elsevier, Amsterdam, 224 pp.

Köppen, W. (1931). Die Klimate der Erde; Grundriss der Klimakunde. 2 Auflage. Walter de Gruijter, Berlin - Leipzig, 369 pp.

Mohr, E.C.S., F.A. van Baren and J. van Schuylenborgh (1972). Tropical Soils. 3rd Ed. Mouton, Ichtiar Baru, Van Hoeve. The Hague - Paris - Jakarta.

Novozamsky, I. and J. Beek (1978). Common solubility equilibrium in soils. In: Bolt, G.H. and M.G.M. Bruggenwert (Eds) - Soil Chemistry A. Basic Elements. Vol.5A. Developments in Soil Science. Elsevier, Amsterdam. p.96-125.

Pomar, J. (1981). Climatologia de La Segarra. In: J. Porta et al. Los Suelos de La Segarra. CPALL, Lleida.

Olsen, S.R. and F.S. Watanabe (1959). Solubility of calcium carbonate in calcareous soil. Soil Sci., Vol.88 (3), p.123-129.

Riba, O. (1976). Geologia dels Paisos Catalans. In: Geografia dels Paisos Catalans. Ketres, Barcelona.

Ruellan, A. (1973). Morphology and distribution of calcareous soils in the Mediterranean and desert regions. In: FAO. Calcareous soils, Soil Bulletin 21. Rome, p.7-15.

Servicio Meteorologio Nacional (1983) Unplubished data. Lleida.

Smith, G.D. (1981). Soil climate in Soil Taxonomy. In: ACSAD (Ed.) - Proceedings Third International Classification Workshop. Damascus, p.1-11.

Smith, G.D. (1982). Conversations in Taxonomy. Soil Survey Horizons. Summer 1982, p.3-10.

Sole Sabaris, L. (1958). Geologia de Catalunya. In: Geografia de Catalunya. Aedos, Barcelona, p.17-222.

Soil Survey Staff (1975). Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook 436, USDA, Washington D.C. 754 pp.

Stuard, D.M. and R.M. Dixon (1973). Water movement and caliche formation in layered arid and semi-arid soils. Soil Sci.Am.Proc. Vol.37, p.323-324.

Thornthwaite, C.W. and J.R. Mather (1955). The water balance. Publ. in Climatology 8(1). Lab. of Climatology. Centerton N.J.

Wieder, M. and D.H. Yaalon (1974). Effect of matrix composition on carbonate nodule crystallization. Geoderma. Vol.11, p.95-121.

Wieder, M. and D.H. Yaalon (1982). Micromorphological fabrics and development stages of carbonate nodular forms related to soil characteristics. Geoderma. Vol.28, p.203-220.

APPENDIX I SOIL DATA

This Appendix comprises the detailed description of the soil profile and the sampling sites, (Appendix IA), as well as the results of the chemical, physical, mineral and micromorphological analyses (Appendices IB, IC, ID). For information on the analytical methods see Appendix II.

The colours are described according to the descriptive terms of Munsell Soil Colour Charts. The horizon designation and description follow the second edition of the "Guidelines for soil profile description" (FAO, 1977).

INFORMATION ON THE SITE.

Profile Number: E-19.

Higher Category Classification:
FAO :Calcic Cambisol
USDA :Calcixerollic Xerochrept, coarse loamy, mixed, mesic.
Date of Examination: 12 October 1984.
Author: J. Boixadera and J. Porta ETSIA Lerida (Spain).
Location: Spain, province of Lerida (La Segarra); 50 m to the right of pathway from Portell to Ferran, at the footslope of the first hill on the left side.
Coordinates: 41°44'20" N and 1°22'10" E.
Topographical map: Guisona, 361 (1 : 50,000).
Elevation: 650 m.
Landform:
i Physiographic position: Bottom of minor valley in a limestone area, in an area of cuestas.
ii Surrounding landform: Flat to rolling (1-15%).
iii Microtopography: Bench terraces with stone walls were built across the valley and also on both sides. Some of them, at the present time, have been removed.
Slope on which profile is sited: Flat (1% on the site).
Landuse: The site is now ploughed for the sowing of winter cereals (barley or wheat) next month.
Climate: Mild humid climate (Köppen, 1931), Mild Mediterranean (Papadakis). Annual rainfall 530 mm (Rocallaura Station) and mean daily minimum and maximum temperatures 7° - 18°C.

INFORMATION ON THE SOIL

Parent material: Colluvial materials from the slopes and also other materials transported by streams, but with a short transport. The materials are mainly from calcareous marls and soils up slope.
Drainage: Well drained.
Moisture conditions in the profile: Slightly moist throughout.
Depth of groundwater: Unknown, but more than 2 m and without any influence on the soil profile.
Presence of surface stones and rock outcrops: Nil.
Evidence of erosion: Slight water deposition.
Presence of salt and alkali: Apparently free.
Human influence: Confined to the ploughed layer.
Position on slope: Midslope.
Exposure of profile: South.

PROFILE DESCRIPTION

Ap 0-26/30 cm Dark brown (7.5 YR 4/4) moist and brown (7.5 YR 5/4) dry; slightly gravelly loam; very weak very fine granular structure; slightly sticky, loose moist, hard; common pores; continuous, slightly compact plough layer (7-10 cm) in the bottom of the horizon; very few tabular-angular gravel size (0.2-6 cm) fragments of hard limestone; calcareous; few, fine and very fine roots, regularly distributed; abrupt, wavy boundary.

Bwt1 26/30-105cm Dark brown (7.5 YR 3/4) moist and light brown (7.5 YR 6/4) dry, slightly gravelly clay loam; strong, very coarse subangular blocky, parting to very strong, coarse granular structure due to fauna activity; slightly sticky, very firm moist, hard; no cementations; common very fine and fine inped and common fine and medium continuous interstitial exped pores; very few tabular-angular gravel size (0.2-6 cm) fragments of hard limestone, regularly distributed and without any orientation; frequent (2-20%) accumulations of lime in the form of discontinuous pseudomycelia; strongly calcareous; few charcoal fragments; frequent signs of biological activity (wormholes, wormcasts, filled burrows); frequent very fine and fine regularly distributed roots; gradual, smooth boundary.

2Bwk2 105-140 cm Light brown (7.5 YR 6/4) moist and pinkish white (7.5 YR 8/2) dry, very gravelly; weak medium subangular blocky structure; slightly sticky, friable moist, hard; no cementations; common fine and very fine pores; very frequent tabular-subangular gravel size (0.2-6 cm) fragments of hard limestone, regularly distributed and with a horizontal orientation; generalized accumulation of lime in the form of hard pendants, with a thickness less than 5 mm; strongly calcareous; few very fine and fine vertical, regularly distributed roots; clear, smooth boundary.

3Ck1 140-150 cm Reddish yellow (7.5 YR 6/6) moist and pinkish white (7.5 YR 8/2) dry, very gravelly; massive, friable moist; very frequent tabular-angular gravel size (0.6-6 cm) fragments of hard limestone, regularly distributed and with a horizontal orientation; generalized accumulation of lime in the form of hard lime beards, less than 5 mm thick on all the limestone gravels, forming discontinuous layers weakly cemented; no roots; clear, smooth boundary.

4Ck2 150-180 cm Reddish yellow (7.5 YR 6/6) moist, very gravelly; massive; friable moist; very frequent subangular-tabular gravel size (0.6-6 cm) fragments of hard limestone, regularly distributed and with a horizontal orientation; generalized accumulation of lime in the form of hard lime beards, less than 5 mm thick on all the limestone gravels, forming discontinuous layers very weakly cemented; no roots; abrupt smooth boundary.

5R 180-200cm+ Hard strata of limestone, cracked in some places (>10 cm) with hard depositions of lime in the cracks and on the lower part of the layers.

INFORMATION ON THE SITE

Profile Number: E-20

Higher Category Classification:
FAO :Calcic Cambisol.
USDA :Petrocalcic Xerochrept, fine loamy, carbonatic, mesic.
Date of examination: 12 October 1984.
Author: M.L. Acevedo, J. Porta and J. Boixadera, ETSIA Lerida (Spain).
Location: Spain, province of Lerida (La Segarra). On the right hand side of the road St. Ramon - Calaf, 100 m before the junction of this route with the route to Tora.
Coordinates: 41°43'30" N and 1°21'40" E.
Topographical map: Guisona, 361 (1 : 50,000).
Elevation: 700 m.
Landform:
i Physiographic position: Cuesta, in a limestone and calcareous marl area.
ii Surrounding landform: Undulating (2-5%).
iii Microtopography: Bench terraces with stone walls.
Slope on which profile is sited: Almost flat (2% of slope).
Landuse: Winter cereals.
Climate: Mild humid climate (Köppen, 1931), Mild Mediterranean (Papadakis). Annual rainfall 530 mm (Rocallaura station) and mean daily minimum and maximum temperature 7° - 18°C.

GENERAL INFORMATION ON THE SOIL

Parent material: Calcareous rock (marl, calcareous marl, siltstone and limestone).
Drainage: Well drained.
Moisture conditions in the profile: Slightly moist throughout.
Depth of groundwater: Unknown, but several meters deep and without any influence on the soil.
Presence of surface stones and rock outcrops: Fairly stony (fragments of a petrocalcic horizon).
Evidence of erosion: Non visible on the surface now, but the profile is truncated.
Presence of salts and alkali: Nil.
Human influence: Deep ploughing. That work has put the fragments of the petrocalcic horizon at the surface and mixed the Ap and B horizon with the calcic and petrocalcic.
Position on slope: On the upper part.
Exposure of profile: SW.

PROFILE DESCkIPTION

Ap 0-22/25 cm Dark brown (7.5 YR 3/4) moist and light brown (7.5 YR 6/4) dry, slightly gravelly silty loam; weak medium granular structure; slightly sticky; friable moist, hard; few spheroidal-subrounded gravel size (0.2-6 cm) fragments of hard accumulations of lime (petrocalcic horizon), without any defined orientation and regularly distributed; strongly calcareous; frequent very fine and fine roots; abrupt wavy boundary.

Bw	22/25-39 cm	Pink (5YR 7/4) moist and pinkish white (5YR 8/2) dry, gravelly clay loam; weak fine subangular blocky structure; slightly sticky, friable moist, hard; no cementations; frequent tabular-subrounded gravel size (2.0-6.0 cm) fragments of petrocalcic, without any orientation and regularly distributed; accumulation of lime in the form of small nodules (Ø < 0.5 cm); disturbed by ploughing; frequent roots; abrupt, wavy boundary.
Cmk1	39-52 cm	Pink (5YR 7/3) moist; massive; weakly cemented accumulations of lime, somewhat disturbed and broken by deep ploughing; very few roots; abrupt, wavy boundary.
Cmk2	52-65 cm	White (2.5 YR 8/2) moist; massive; strongly cemented, continuous, extremely hard accumulations of lime; no roots; abrupt, wavy boundary.
Cmk3	65-70 cm	Very pale brown (10YR 7/3) moist; very strongly cemented, discontinuous, extremely hard accumulations of lime; no roots; abrupt, wavy boundary.
Cmk4	70-75 cm	(10YR 7/3) moist; very strongly cemented in some parts, extremely hard accumulations of lime; no roots; abrupt wavy boundary.
2R	75-80+ cm	Hard strata of limestone; cracked in some places (> 10 cm) with hard depositions of lime on the cracks and in the lower part of the layers.

APPENDIX IB LABORATORY DATA
(Analyses carried out by the International Soil Reference and Information Centre).

HORIZON	SAMPLE DEPTH (cm)	GRAVEL	PARTICLE SIZE DISTRIBUTION (m in weight %) sand					silt		clay	pH		CaCO	C	EC
		> 2 mm	2000 1000	1000 500	500 250	250 100	100 50	50 20	20 2	< 2	H O 1/2.5	KCl	%	%	1/2.5 mS/cm
AP	0- 26	8.0	0.0	0.5	6.0	14.6	10.4	23.0	18.5	26.9	8.0	7.2	9.8	1.13	0.24
Bwt1	26- 52	4.8	0.0	0.5	5.9	14.0	11.0	19.8	22.0	26.7	8.2	7.3	8.8	0.62	0.19
Bwt1	80-105	7.9	0.1	0.6	5.5	11.4	8.5	21.0	22.1	30.9	8.1	7.2	8.5	0.79	0.29
2Bwk2	105-140	40	0.0	1.2	11.3	20.1	11.5	15.6	15.3	25.0*	8.0	7.6	56.4	0.82	0.51
3Ck1	140-150	69	0.3	0.5	3.1	6.3	6.0	14.6	11.0	58.1*	8.3	7.7	75.8	0.28	0.33
4Ck2	150-180	58	0.4	0.4	1.7	4.9	7.3	4.5	16.9	63.9*	8.4	7.7	73.1	0.13	0.22
Bwt1	40-50	4.7												0.52	
Bwt1	65-75	5.5												0.70	
Bwt1	90-100	5.9												0.83	
2Bwk2	125	43.7												0.93	

* decarbonated with 4 N HCl

		Na-Dit extr.				Amm.Ox. extr			Na-Pos extr.	
		Fe	Al	Si	Mn	Fe - % -	Al	Si	Fe	Al
Ap	0- 26	1.03	0.07	0.10	0.05	0.08	0.10	0.05	0.01	0.02
Bwt1	26- 52	1.07	0.08	0.11	0.05	0.08	0.11	0.04	0.01	0.02
Bwt1	80-105	1.16	0.11	0.11	0.06	0.08	0.17	0.04	0.01	0.03
2Bwk2	105-140	0.43	0.04	0.04	0.02	0.02	0.12	0.01	0.00	0.02
3Ck1	140-150	0.29	0.02	0.05	0.02	0.01	0.03	0.01	0.00	0.02
4Ck	150-180	0.38	0.02	0.05	0.03	0.01	0.02	0.02	0.00	0.02

HORIZON	SAMPLE DEPTH (cm)	EXCHANGEABLE CATIONS meq/100 g.							
		NH OAc method							
		Ca	Mg	Na	K	Sum	CEC	Sat	S/T(%)
Ap	0- 26	23.4	0.8	0.0	0.6	24.9	15.6	sat	160
Bwt1	26- 52	23.0	0.8	0.2	0.4	24.4	13.6	sat	179
Bwt1	80-105	26.6	1.0	0.2	0.4	28.2	16.6	sat	169
2Bwk2	105-140								
3Ck1	140-150								
4Ck2	150-180								
		BASCOMP method							
		Ca	Mg	Na	K	Sum	CEC	Sat	S/T(%)
Ap	0- 26	21.2	0.6	0.0	0.1	22.2	17.6	sat	126
Bwt1	26- 52	20.1	0.7	0.1	0.2	21.1	16.3	sat	129
Bwt1	80-105	25.8	0.9	0.0	0.2	26.9	14.6	sat	184
2Bwk2	105-140	61.5	0.5	0.1	0.1	62.2	12.2	sat	510
3Ck1	140-150	41.6	0.4	0.1	0.1	45.2	9.2	sat	491
4Ck2	150-180								
		LI-EDTA method							
		Ca	Mg	Na	K	Sum	CEC	Sat	S/T(%)
Ap	0- 26	19.2	1.4	0.1	0.0	20.6	15.3	sat	135
Bwt1	26- 52	17.2	1.4	0.1	0.0	18.6	13.4	sat	139
Bwt1	80-105	18.5	1.7	0.0	0.5	20.7	16.3	sat	127
2Bwk2	105-140	7.0	0.4	0.1	0.0	7.5	6.8	sat	110
3Ck1	140-150								
4Ck2	150-180								

HORIZON	SAMPLE DEPTH (cm)	MOISTURE RETENTION (wt %). pF 0.0	pF 1.0	pF 1.5	pF 2.0	pF 2.3	pF 2.7	pF 3.5	pF 4.2	Bulk dens (g/cm)
Ap	0- 26	48.51	44.98	37.39	28.43	25.51	21.28	13.38	11.31	1.20
Bwt1	26- 36	43.36	41.38	36.46	30.56	28.08	24.21	16.00	13.72	1.45
Bwt1	50- 65	42.72	39.14	32.63	27.55	25.76	22.63	20.03	18.21	1.50
2Bwk2	120-130	43.88	41.11	34.88	27.61	24.86	20.41	23.18	19.26	1.38
4Ck2	160-170	38.87	32.56	22.88	17.69	16.14	13.78	9.47	7.25	1.31

		CLAY MINERALOGY (X-ray diffraction) Kaol	Mi/Ill	Chlor	Smec	Quar	Goeth
Ap	0- 26	tr-+	+	tr-+	+	tr-+	0-tr
Bwt1	26- 52	tr-+	+	tr-+	+	tr-+	0-tr
Bwt1	80-105	+	+	tr-+	+	tr-+	tr
2Bwk2	105-140	+	+	tr-+	+	tr	tr
3Ck1	140-150	+	+	tr-+	+	tr-+	tr
4Ck2	150-180	+	+	tr-+	+	tr-+	tr

HORIZON	SAMPLE DEPTH	GRAVEL	PARTICLE SIZE DISTRIBUTION (m in weight %)								pH		CaCO	C	EC
			sand					silt		clay					
	(cm)	> 2 mm	2000 1000	1000 500	500 250	250 100	100 50	50 20	20 2	< 2	H O 1/2.5	KCl	%	%	1/2.5 mS/cm
Ap	0-22	16	0.1	0.1	1.7	9.1	15.1	30.9	26.3	16.8*	7.9	7.3	35.5	1.26	0.30
Bw	22-39	8	0.1	0.1	3.8	18.0	13.1	17.2	19.3	28.4*	7.9	7.7	72.1	0.83	0.38
Cmk1	39-52										8.2	7.9	91.3	0.55	0.29
Cmk2	52-65										8.5	8.3	99.7	0.32	0.24
Cmk3	65-70										8.1	7.8	96.5	1.11	0.30
Cmk4	70-75	8.6									8.2	8.0	97.2	0.83	0.27
	Bult														

* decarbonated with 4 N HCl

		Na-Dit extr.				Amm.Ox. extr			Na-Pos extr.	
		Fe	Al	Si	Mn	Fe - % -	Al	Si	Fe	Al
Ap	0-22	0.79	0.06	0.04	0.02	0.06	0.09	0.03	0.01	0.03
Bw	22-39	0.37	0.04	0.03	0.01	0.01	0.07	0.01	0.01	0.04
Cmk1	39-52	0.22	0.02	0.02	0.01	0.00	0.02	0.01	0.00	0.04
Cmk2	52-65	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01
Cmk3	65-70	0.09	0.02	0.03	0.00	0.00	0.02	0.01	0.01	0.04
Cmk4	70-75	0.04	0.02	0.04	0.00	0.00	0.01	0.01	0.00	0.02

HORIZON	SAMPLE DEPTH (CM)	EXCHANGEABLE CATIONS meq/100 g.							
		BASCOMP method							
		Ca	Mg	Na	K	Sum	CEC	Sat	V/T(%)
Ap	0-22	24.7	0.4	0.0	0.2	25.3	18.6	sat	136
Bw	22-39	36.7	0.2	0.0	0.1	37.0	12.8	sat	289
		LI-EDTA method							
		Ca	Mg	Na	K	Sum	CEC	Sat	S/T(%)
Ap	0-22	13.4	0.6	0.0	0.0	14.0	10.3	sat	136
Bw	22-39	6.9	0.3	0.1	0.0	7.2	7.7	sat	94

HORIZON	SAMPLE DEPTH (cm)	MOISTURE RETENTION (wt %).								
		pF 0.0	pF 1.0	pF 1.5	pF 2.0	pF 2.3	pF 2.7	pF 3.5	pF 4.2	Bulk dens (g/cm)
Ap	10-20	52.55	50.79	47.31	39.13	35.86	30.76	22.49	18.96	1.48
Bw	30-40	56.1	54.60	47.40	41.70	39.21	33.79	26.11	22.15	1.35

		CLAY MINERALOGY (X-ray diffraction)						
		Kaol	Mi/Ill	Chlor	Smec	Mi-Chlor	Quar	Feld
Ap	0-22	+	+	+	+	-	0-tr	0-tr
Bw	22-39	+	+	+	+	-	0-tr	0-tr
Cmk1	39-52	+	+	tr-+	+	-	0-tr	0-tr
Cmk2	52-65	tr-+	tr-+	-	tr-+	tr-+	0-tr	0-tr
Cmk3	65-70	tr-+	tr-+	-	tr-+	tr-+	0-tr	0-tr
Cmk4	70-75	tr-+	tr-+	-	+	tr-+	0-tr	0-tr

PROFILE E-19

Thin sections: 2772, 5 - 20 cm, Ap horizon
2773, 26 - 41 cm, Bwt1
2774, 67 - 82 cm, Bwt1
2775, 87 - 103 cm, Bwt1
2776, 110 - 125 cm, 2Bwk2.

Ap horizon
Thin section 2772, 5 - 20 cm.

Macroscopic
The soil material is uniform strong brown (7.5 YR), medium textured (clay + silt) with some coarse fragments of limestone ranging from sand size to gravel size. The material is crumbly and subangular blocky with fine channels traversing it.

Microscopic
Microstructure
The microstructure is complex: small, more or less dense subang.bl. granules, Ø up to 150 Um - and crumblyu aggregates areformed with strongly varying size - Ø 0.5 mm-8 mm -. These aggregations are united in faint, loosely packed subang.bl. peds - Ø 2.5-3 cm -. Similar aggregations larger than 8 mm up to Ø 3 cm take the shape of independent subang.bl. peds.
Hence, porosity is very high - 30% S.A. - and intricate: very irregular planes between voids, in case granules and crumbs together are forming the peds. The more dense peds internally display small vughs and planes. Common to few channels and root channels traverse the material. Generally the void walls are rough, and the voids show no orientation.

The groundmass
The c/f limit is set at 10 Um. the fine mass is composed of mineral clay, very fine CaCO (micrite) and other grains, organic colloids and punctuations, all at random, together covering approximately 30% S.A.
The clay has a strong brown colour. It shows no orientation features. Staining is due to the organic colloids and Fe-compounds. Limpidity is speckled.
The b-fabric is undifferentiated with regard to the clay, but regarding the micrite present it is termed crystallitic (calciasepic after Mulders).
The coarse grains dominantly consist of quartz, some feldspar and micaceous quartzites. Coarse mineral grains, larger than 100 Um are rounded or subrounded . They cover approx. 10% S.A. Smaller coarse grains mostly are not rounded. They cover 30%-40% S.A.
Common to many coarse organic particles, dominantly organ and tissue residues. When root remains are recognizable they mostly display mining with ageing excrements. The colour of the organic remains mostly is very dark brown to opaque.
The related distribution is porphyric, sillipsam/sillipel ratio 3/4-5.

The pedofeatures
The crumbly character of the soil material along with a strong diminution of plant fragments and the random distribution of the organic remains indicate a strong activity of soil fauna. Loose infillings in interpedal

* Micromorphological description by R.O. Bleijert (ISRIC).

spaces are common. They are composed of rounded granules ∅ up to 100 Um and small crumbs ∅ up to 1 mm.
Some of the coarse grains display very faint argillic grain coatings. Single $CaCO_3$ crystals and their intergrowths embedded in the groundmass are common to many. The crystals strongly vary in size with ∅ up to 150 Um, but mostly thay are smaller than 50 Um, all in a random distribution.
Occurring $CaCO_3$ nodules are partly regarded as relicts - fossil formations of the limestone -. The relicts mostly are irregular internal fabric as the underlying material from which they are assumed to split off. These lithorelicts partly contain spherical bodies.
However, some of the nodules are formed pedogenetically (see Nr 2775).

Bwtl horizon
Thin sections 2773, 2774 and 2775, 26 cm - 103 cm.

Macroscopic
The soil material is uniform strong brown (7.5 YR). Nr. 2773 and 2774 are very similar in colour to Nr. 2772, but Nr. 2775 is somewhat lighter (higher in value). All three thin sections are medium textured (clay + silt) with coarse limestone fragments ranging from sand size to gravel size.
No peds are identified in the thin sections, only a few large cracks may indicate pedality. Compacted granules and crumbs constitute the material. Porosity mainly results from their packing but fine channels are superimposed.

Microscopic
The microstructure is intricate: compacted granules and crumbs, the latter mostly are partly delimited by planes and vughs. The vughs strongly vary in size and shape (often mammilated) and may be interconnected. Internally the crumbs have smaller vughs or compound packing voids (packing of granules) with ∅ up to 450 Um. Hence, the type of microstructure is complex: basically crumbly and internally the crumbs are vughy and channelled. Porosity is moderate to high (15% - 25% S.A.); locally higher. The planes often are curved and rough walled. Vughs delimiting crumbs are often mammilated and rough walled as well; internal vughs and compound packing voids are crenulate. Channels may be elongated or vesicular in shape and they have smooth to crenulate walls. The voids show no orientation.

The groundmass
The c/f limit is set at 10 Um. The finemass is similar to Nr. 2772, but the following remarks have to be made:
- with depth the content of micrite increases very gradually but continuously to a depth of 97 cm. Below 97 cm local $CaCO_3$ concentrations are evident. (Note that part of the $CaCO_3$ nodules may originate from such accumulations).
- the colour value increases with depth due to a decrease of the frequency of punctuations and organic colloids: Nr. 2775 evidently is lighter in colour.
- the coarse materials are identical to Nr. 2772 but below approx. 30 cm depth the number of organic remains is evidently lower (very few).
- tabular fragments of limestone are oriented more or less parallel to the surface or are inclined. Related distribution as before.

The pedofeatures

- Very faint, very thin argillic coatings on a few voidwalls can be observed down to approximately 97 cm depth. In Nr. 2774 they are developed best. They are unspectacular because of their low thickness, low birefringence and little difference in colour as compared with the groundmass.

- With depth there is an increasing number of voids with some lublinite crystals developed on their walls, in some cases forming discontinuous lublinitans. In Nr. 2775 the lublinite may occur together with the argillic coatings mentioned before.

- With depth the amount of micrite in the groundmass increases gradually to a depth of 97 cm. From here to a depth of 103 cm there is an evidently higher amount of micrite in the groundmass but especially local accumulations have to be noticed. The boundary of the accumulations is more or less diffuse and part of them is fractured.

- The number and size of single $CaCO$ crystals and intergrowths increase with depth. In accumulation locations their frequency is even higher.

2Bwk2 horizon
Thin section 2776, 110 - 125 cm.

Macroscopic
The material is uniform pale brown (10YR), medium textured (clay + silt), with many both tabular and more spherical limestone fragments, ranging from sand size to gravel size. The fragments are rounded and the sphericity increases as they get smaller, finally taking the shape of nodules.
Pedality is weak, medium subangular blocky. The interior of peds is more or less dense, dominantly with small vughs and channels.

Microscopic
Microstructure is intricate: rounded, loosely aggregated granules Ø up to 100 Um which internally are dense and crumbs Ø up to approx. 2 mm are formed. The crumbs either are dense or display compound packing voids up to 50 Um.
The packing of granules and crumbs is such that thay are loose to strongly compacted, and so larger compound packing voids and vughs, locally short planes, result. Superimposed channels are present.
Crumbs and granules are united in weak medium subangular blocky peds. Hence, microstructure is complex and the porosity is fairly high: part of it is due to biological activity.

The groundmass
The c/f limit is set at 10 Um. The finemass is strongly micritic and very poor in organic components.
The finemass has a pronounced crystallitic b-fabric.
Coarse mineral grains are identical to the thin sections before, but here the quartz grains are dominant and the S.A. covered is evidently lower: 5%.
Coarse organic remains were not detected.
The related distribution is porphyric pelisil/sillipsam, ratio 2/8.

The pedofeatures

- Lublinite occurs in the greater part of the voids but not spectacular, sometimes very poorly and sometimes moderately developed.
- Single CaCO crystals and intergrowths are well developed and frequent.
- CaCO root pseudomorphs are a common feature (elongated and circular transsections).
- Argillic coatings are not observed.

PROFILE E-20

Thin sections: 2779, 5 - 20 cm, Ap horizon
2780, 20 - 35 cm, lower Ap and Bw horizon
2781, 39 - 45 cm, Cmk1
2782, 48 - 55 cm, Cmk2
2783, 55 - 60 cm, Cmk2
2784, 65 - 70 cm, Cmk3

Ap horizon
Thin section 2779, 5 - 20 cm.
(the description includes the upper 3 cm of thin section Nr. 2780)

Macroscopic
The soil material is uniform strong brown (7.5 YR), medium textured (clay + silt), gravelly.
The upper 10 - 12 cm displays a complex porosity and aggregation: granules and crumbs in a loose packing but with few nodular like soil aggregates. Below 12 cm depth to approx. 23 cm depth the granules and crumbs are partly united in subangular blocky peds, locally forming a continuous mass traversed by very fine planes.
Gravel size grains consist of calcareous rock fragments. They often display (hypo)coatings, either on one side of the grain or totally surrounding it. Mostly they are irregular and subrounded. Smaller fragments are spheroidal. Porosity is high, dominantly packing voids between the granules and crumbs, but also planes between the peds and/or within the continuous masses make a contribution.

Microscopic
Microstructure
In the upper 10 - 12 cm the microstructure is complex: composed of granules up to 150 Um and crumbs of 1.5 - 8 mm. The granules mostly are composed of clay, very fine silt size mineral grains and very fine grained CaCO . The crumbs include rather spherical CaCO fragments ranging in size up to 500 Um. Larger CaCO fragments normally are not incorporated in aggregations (single, loose) in the upper 12 cm, but below that depth they contribute to peds.
The voids in the upper 12 cm are packing voids strongly varying in size, due to the size of the aggregations and the density of their packing. Internally the density of the crumbs may vary strongly due to the packing of granules: compound packing voids may be the case or small vughs up to 50 Um and even very fine planes can be observed Ø up to 800 Um. Planar voids between the peds may reach Ø up to 800 Um. The peds display internal vughs up to 150 Um and fine planes up to Ø 50 Um.

The groundmass
c/f limit is set at 10 Um. The fine material consists of clay with organic punctuations, fine carbonate grains (micrite) and dominantly silt size mineral grains covering approx. 5% of the S.A.
The clay has a strong brown colour and shows no orientation features. Staining is due to organic colloids, punctuations and to a minor extent to Fe-compounds. Limpidity is speckled. The b-fabric is undifferentiated with regard to the clay, but with regard to the micrite present, it is termed crystallitic (calciasepic, after Mulders, 1969).
The coarse material mainly consists of quartz and some feldspar grains, few splinters of biotite. Carbonate fragments are common to many. Internally

they display globular bodies, very similar to the spheroidal fragments mentioned in the macroscopic description.
Coarse organic particles are few, mostly fragments of fine and very fine roots and partly showing intact organic feacal pellets. Mostly the central tissues vanish first.
The $c/f_{10\ Um}$ related distribution is porphyric psammi-sil/silli-pel, ratio 7/3.

The pedofeatures
The globular carbonate "nodules" are regarded as fossil formations of the underlying material. Some of them internally display lublinite needles in their cavities. Some have ferric hypo-coatings impregnating the fine crystalline interior.
The most obvious recent pedofeatures are single crystals of CaCO with a size up to 150 Um. Locally twinning is the case thus forming somewhat larger units (intergrowths). Some of the carbonate "nodules" have a concentric fabric, the outer layer of which is relatively richer in clay and quartz grains of silt size. Possibly this layer is formed pedogenetically by accretion around the inner material.

Bw horizon
Thin section 2780, 20-35 cm.
(the upper 3 cm are described in 2779)

Macroscopic
The soil material is uniform strong brown to reddish yellow (7.5 YR), medium textured (clay + silt), gravelly. There is a sharp abrupt boundary to the overlying material.
Between 23 and 26 cm the material is crumbly; below 26 cm, more or less, strongly compacted crumbs to apedal with a few cracks and common to many channels. Still the porosity is fair. Between 23 and 28 cm depth infillings composed of overlying material are observed.
Elongated carbonate fragments are oriented parallel to the surface. Also here these smaller carbonate fragments are rounded and subrounded. Commonly the carbonate fragments display (hypo)coatings.

Microscopic
Microstructure
Between 23 and 28 cm depth the microstructure is complex; crumbly to fine subangular blocky, locally with zones of more or less compacted granules. Hence, a very intricate void pattern is displayed dominated by packing voids, which strongly vary in size, and planes; root channels and animal burrows superimposed at random. At 26 cm depth there is an abrupt boundary due to an increased compaction. Peds are not observed, just a single, more or less vertical crack. Here the groundmass displays local zones of aggregating granules and compacted crumbs whith a rather low internal porosity (vughs Ø up to 100 Um). Small planes and somewhat larger vughs up to 250 Um indicate the deliniation of original crumbs resp. subangular blocky aggregates. Channels are superimposed.

The groundmass
The groundmass essentially is similar to the material as described for the previous thin section with the following differences:
In the fine mass there is a relatively low amount of organic colloids and punctuations, but on the other hand the amount of micrite has markedly increased.

Coarse grains and related distribution are similar to thin section Nr.2779.

The pedofeatures
Essentially the same as before, but the number and the size of single carbonate crystals as well as the intergrowths have increased.
Cutans of lublinite occurring on walls of voids of the groundmass are a common feature and so are cutans composed of newly formed micrite. In some cases both forms occur together.

Cmkl horizon
Thin section 2781, 39 - 45 cm.

Macroscopic
The soil material is uniform reddish yellow (7.5 YR), medium textured, gravelly. Porosity is moderate, that is, very small interconnected vughs are dominant (10% S.A.), in some cases merging into planar voids. Gravel as described before. Especially the smaller carbonate relicts frequently are stained strong brown (7.5 YR) and have a speroidal shape.

Microscopic
Microstructure
The apedal material is vughy. The vughs have ∅ up to 300 Um, but normally approximately 150 Um, often interconnected forming irregular planar voids which are rough. The distribution is at random.

The groundmass
The groundmass is similar to previous thin section.

The pedofeatures
The pedofeatures are similar to previous thin section.

Cmk2, Cmk3 horizon
Thin sections 2782, 2783 and 2784, 48 - 70 cm.

Macroscopic
In the soil monolith it can be observed that essentially the material consists of fragmented carbonates with some weathered material between the fragments. The thin sections display these fragments. In Nr. 2784 some of the weathered material is also present. Of both kinds of material a short characterisation is given:
- The carbonate fragments display a laminated fabric: limestone composed of a fine groundmass in which nodular bodies are embedded. The groundmass displays a weak pattern of cracks which delineate subangular blocky aggregates: a moderate porosity and a fine subangular blocky microstructure is the case. Interlayers are compact, do not display cracking and mostly they are free of nodular bodies.
- The weathered material principally is similar to the previous thin section, but the colour is very weak reddish yellow (7.5 YR) to yellow (10 YR). Here only a smaller part of the carbonate fragments bear a coating.

Microscopic
Microstructure and groundmass of the slightly weathered materials are similar to the material in Nr. 2781.
Pedofeatures are cutanic lublinite and micrite, mostly occurring together.

APPENDIX II ANALYTICAL METHODS

Particle size distribution

Cementing materials are removed by mild acid (pH 5) buffer of NaOAc/HOAc and H_2O_2. The last is only added after cessation of effervescence and subsequent decantation and centrifuge washing, to avoid formation of Ca-oxalate. Dispersion with sodium pyrophosphate. Particles larger than 50 μm are separated by sieving; smaller particles by the pipette method.

Samples which are calcareous too (horizons 2Bwk2, 3Ck1, 4Ck2 from profile E-19 and horizons Ap and Bw from profile E-20), instead of the treatment with the mild acid, were treated with 4N HCl.

pH

The pH was measured in a 1 : 2.5 air dry soil : water (wt/wt) suspension after overnight mechanical shaking.
The pH-KCl was similarly measured using 1N KCl solution instead of water.

Organic Carbon

Organic carbon was determined according to the Walkley Black method.

Free iron oxide

To determine different forms of "free" iron oxide, extractions were made with three different extractants (reviewed by Andriesse, 1979). Dithionite (Holmggren, 1967) : 2 g of air-dry fine earth was shaken overnight with a sodium citrate/sodium dithionite mixture and then centrifuged.

Oxalate : 2 g of air-dry fine earth was shaken for 4 hours in 200 ml Tammis solution (0.2 M ammonium oxalate, pH 3, i.e. acidified with ca 20 g oxalic acid per litre) and then centrifuged.

In all cases superfloc was added prior to centrifugation. Fe, Al, Si and Mn were determined by Atomic Absorption Spectrophotometer (AAS), Fe with air/C_2H_2 flametype and the others with NO_2/C_2H_2 flametype.

Exchangeable cations and cation exchange capacity (CEC)

Three different methods were used:
- Standard percolation with ammonium acetate pH = 7
- Bascomp (modified) method
- Li - EDTA method

Calcium and magnesium were determined by AAS and sodium and potassium by AES in the leachate.

Electrical conductivity

Measured in the 1 : 2.5 pH-H_2O suspension.

Clay mineralogy

Clay was separated as indicated for particle size analysis, except that the dispersion is done with NaOH instead of pyrophosphate. Approximately 10 mg clay was brought onto a porous plate by suction and the specimens were analyzed on Philips diffractometer. For better identification of the non-phyllosilicates Guinier photos were taken of the concretions.

The relative abundance of the minerals in the clay fraction is indicated by the number of + for clay minerals and x for other minerals.

Moisture characteristics

pF were constructed by equilibrating undisturbed ring samples at different suction values (low tension range) in individual tempe presure cells and high suction (15 bar or approximately pF 4.2) values were obtained from disturbed sample in high pressure cells.

From the obtained pF curve the available moisture between Field-capacity and wilting point is derived.

Bulk density

It was determined from dry weight of undisturbed sample of metal sampling tube.

APPENDIX III   SOIL MOISTURE REGIME

Available water capacity (AWC)

The AWC is computed for profiles E-19 and E-20 using analytical data (Appendix II) and the field description (Appendix I). The soil is considered to be dry when the soil water is held at a tension of 15 bars (pF = 4.2). From the morphological description it can be seen that the groundwater table is very deep and it does not supply any water to the soil; the limit of the so called field capacity can be placed in the present case at a tension of 1/10 bar (pF = 2) because at that tension the movement of water in the soil is very restricted.

Pedon E-19 has a hard limestone rock at 180 cm depth and it is impenetrable to roots, the lower limit of the soil being set up at that depth.

Pedon E-20 has a cemented accumulation of CaCO from 39 cm downwards. That cementation includes also parts less cemented, but the degree of cementation increases with depth. It can be termed a petrocalcic horizon and from observation in similar pedons in the area it can be concluded that roots of some perennials (grapes, almonds, carob, pines) can grow through the petrocalcic and take some of the moisture which is stored in the pores. However, becuase root growth is very restricted to the cracks, the high lime content induces chlorosis and most of the plants are not able to grow in this horizon, the AWC of the petrocalcic horizon is disregarded and it is not taken into account for the present computations.

TABLE 1-III Available water capacity (AWC) in mm of pedons E-19 and E-20.

Pedon	Horizon	Depth (cm)	AWC (mm/10 cm)	AWC (mm/hor)	AWC (mm)
E-19	Ap	0- 26	17	44	
	Bwt1	26-105	13	103	
	2Bwk2	105-140	8	20	
	3Ck1, 4Ck2	140-180	10	40	207
E-20	Ap	0- 22	20	44	
	Bw	22- 39	19	32	76

The calculations summarized in Table 1-III show an AWC of 76 mm for profile E-20. If several rooting depths are considered in E-19 AWC amounts 75 mm for shallow ones (50 cm), 159 mm for deep ones (120 cm) and 207 mm for very deep ones.

Soil moisture control section (SMCS)

The intent in its definition is to estimate soil moisture regimes from climatic data (Soil Survey Staff, 1975). Making use of the analytical data from Appendix II, it is estimated that profile E-19 has a SMCS from 15 cm to 50 cm and profile E-20 from 13 cm to 38 cm. That estimation is a signification, because it must be determined in the field. However, from the field observation it seems clear that infiltration is not a restriction for the present method. The lower limit of SMCS must be in good agreement with the field situation becuase pF = 2 corresponds to a soil moisture 2-3 days after rain. The upper limit can be somewhat less than calculated.

APPENDIX III

TABLE 2-III Waterbalance according to Thornthwaite - Mather for profiles E-19 and E-20, using data from Cervera station.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
P	25.8	24.3	40.4	46.7	60.4	43.6	20.3	37.7	48.5	55.1	35.5	34.8	473
PE	12.4	19.6	65.1	111	155	168.6	215	189	144	100.5	21.0	12.0	1213
P-PE	13.4	4.7	-24.7	-64.3	-94.6	-125	-194.7	-151.3	-95.5	-45.4	14.5	22.8	740
STo = 76mm													
APWL	-	(22.7)	47.4	111.7	206.3	331	526	677	772	818			
ST	50.7	(55)	40	16	4	1	0	0	0	0	14.5	37.3	
ΔST	13.4	4.7	-16	-23	-12	-3	-1	0	0	0	14.5	22.8	
AE	12.4	19.6	56.4	69.7	72.4	46.6	21.3	37.7	48.5	55.1	21.0	12.0	473
D	-	-	8.7	41.3	82.6	122	193.7	151.3	95.5	45.4	-	-	740
S	-	-	-	-	-	-	-	-	-	-	-	-	
STo = 207mm													
APWL	-	(252.4)	276.1	340.4	435	560	754.7	896	1001.5	1046.4	-	-	740
ST	51.7	(56.4)	49	36	22	12	5	2	0	0	15.5	38.3	
ΔST	13.4	4.7	-7.4	-13	-14	-10	-7	-3	-1	0	14.5	22.8	
AE	12.4	19.6	47.8	59.7	74.4	53.6	27.3	40.7	49.5	55.1	21.0	12.0	473
D	-	-	7.3	51.3	80.6	115	187.7	148.3	94.5	45.4	-	-	740
S	-	-	-	-	-	-	-	-	-	-	-	-	

APPENDIX III

Soil temperature regime (STR)

According to SSS (1975) the soil temperature can be estimated as follows, using data from Cervera (Table 1):

- The mean annual summer soil temperature at 50 cm is equal to the average air summer temperature minus 0.6°C. That gives a soil temperature in summer equal to 21.5°C.
- The mean winter soil temperature shows the same deviation from the MAST as the mean summer soil temperature. Thus it will be 6.5°C.

The difference between summer and winter soil temperature is larger than 5°C, which together with the MAST value yields a mesic soil temperature regime.

Water balance. Soil moisture regime.

All the climatic data used in this paragraph is summarized in Table 1 and Table 2. In order to obtain an estimation of the soil moisture regime a detailed water balance according to Thornthwaite and Mather (1955), who used an exponential depletion factor, is carried out for Cervera. To give a more complete picture P-PE diagrams, with PE from the Thornthwaite formula and rainfall from Cervera and Rocallaura are presented. The latter is done trying to have a more realistic value of the precipitation in the soil sites. There is a certain trend of increasing precipitation when height above sea level increases in La Segarra and the soil sites are more than 200 m higher than Cervera, but on a similar height as Rocallaura.

Due to the fact that no probabilistic information about rainfall is available, the calculations are made on an average 25 year basis. However, the following points become clear from the water balance (Table 2-III, fig. 3-III) and the P-PE diagrams (fig. 1-III and 2-III):

a) The AWC is not filled up completely in the average year, because the maximum amount of water in excess over PE in the humid period is, in any case, less than 75 mm.
b) The SMCS is moist in some part for more than half the time when soil temperature at 50 cm is higher than 5°C, that is from October to June.
c) It has a dry SMCS of about 120 days in summer time (July, August, September).
d) The SMCS is completely moist more than 45 days from January to April.
e) It is moist in some parts of the SMCS more than 90 days when the soil temperature is higher than 8°C at 50 cm.

From the aforementioned points and taking into account that the soil temperature regime is Mesic, it can be concluded that the soil moisture regime is Xeric, with a dry period in summer (July, August, September) and a humid period where precipitation exceeds potential evapotranspiration (November, December, January, February).

That conclusion is also in agreement with the present landuse. Mainly winter cereals are grown on both soils in rainfed agriculture, without application of dry farming techniques and with a reasonable success most of the years. That fits in the concept of the Xeric moisture regime (Smith, 1981). Only deep rooted perennial Mediterranean crops (almonds, grapes, olives) are grown in similar soils, other crops being absent.

APPENDIX III

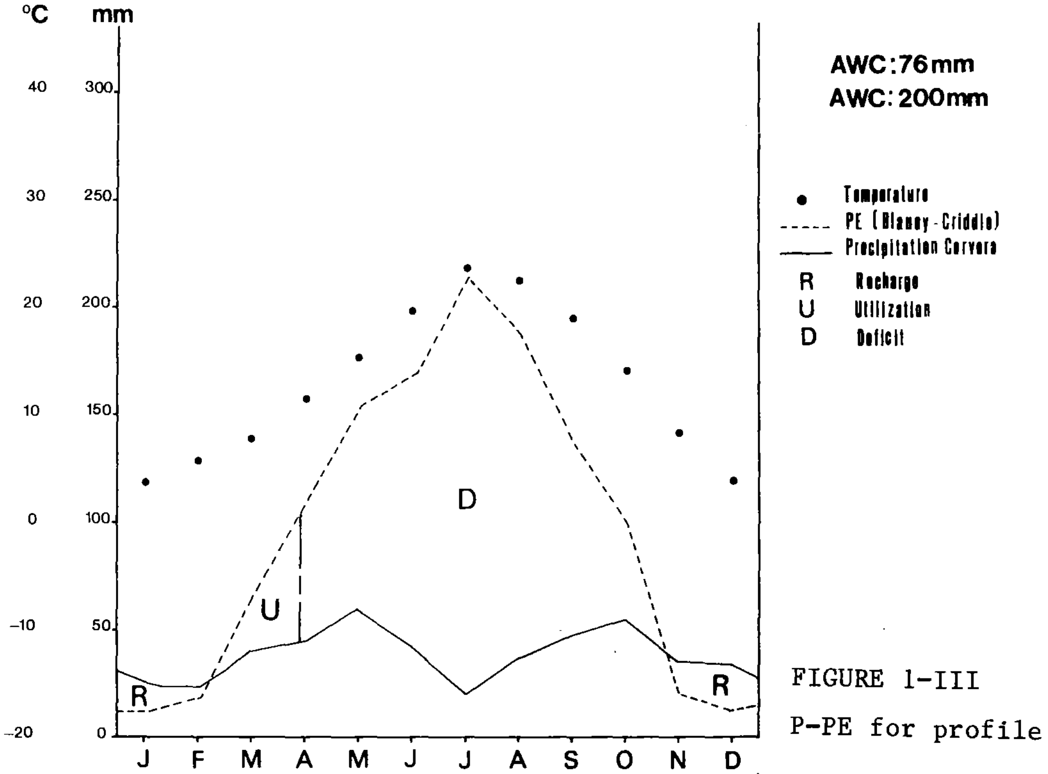


FIGURE 1-III

P-PE for profile E-19

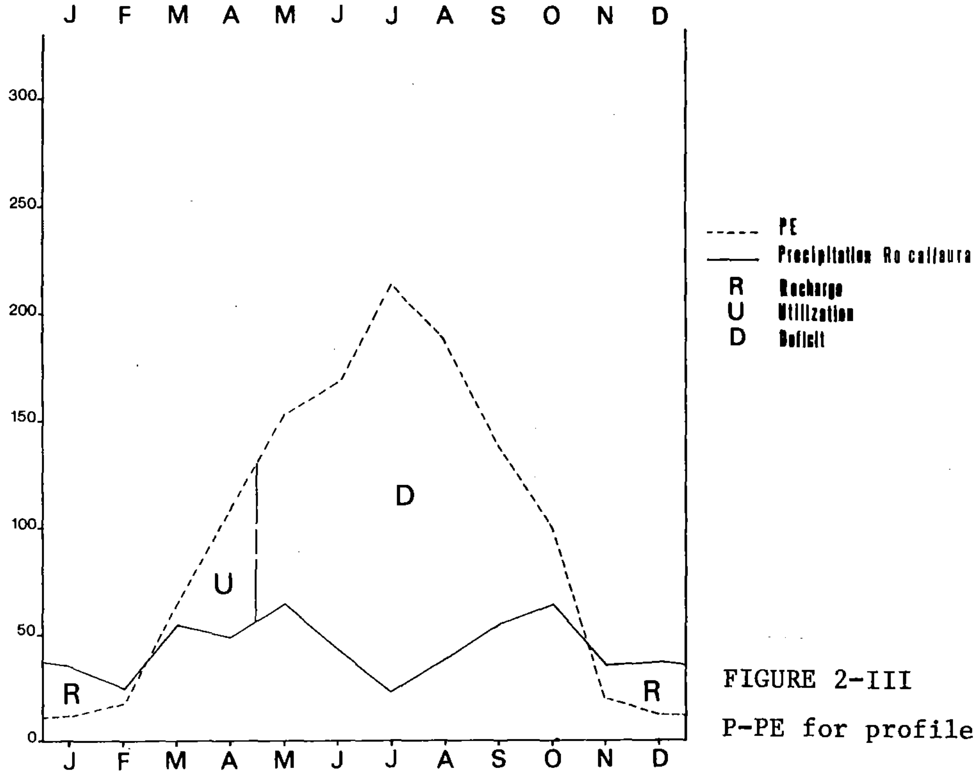


FIGURE 2-III

P-PE for profile E-20

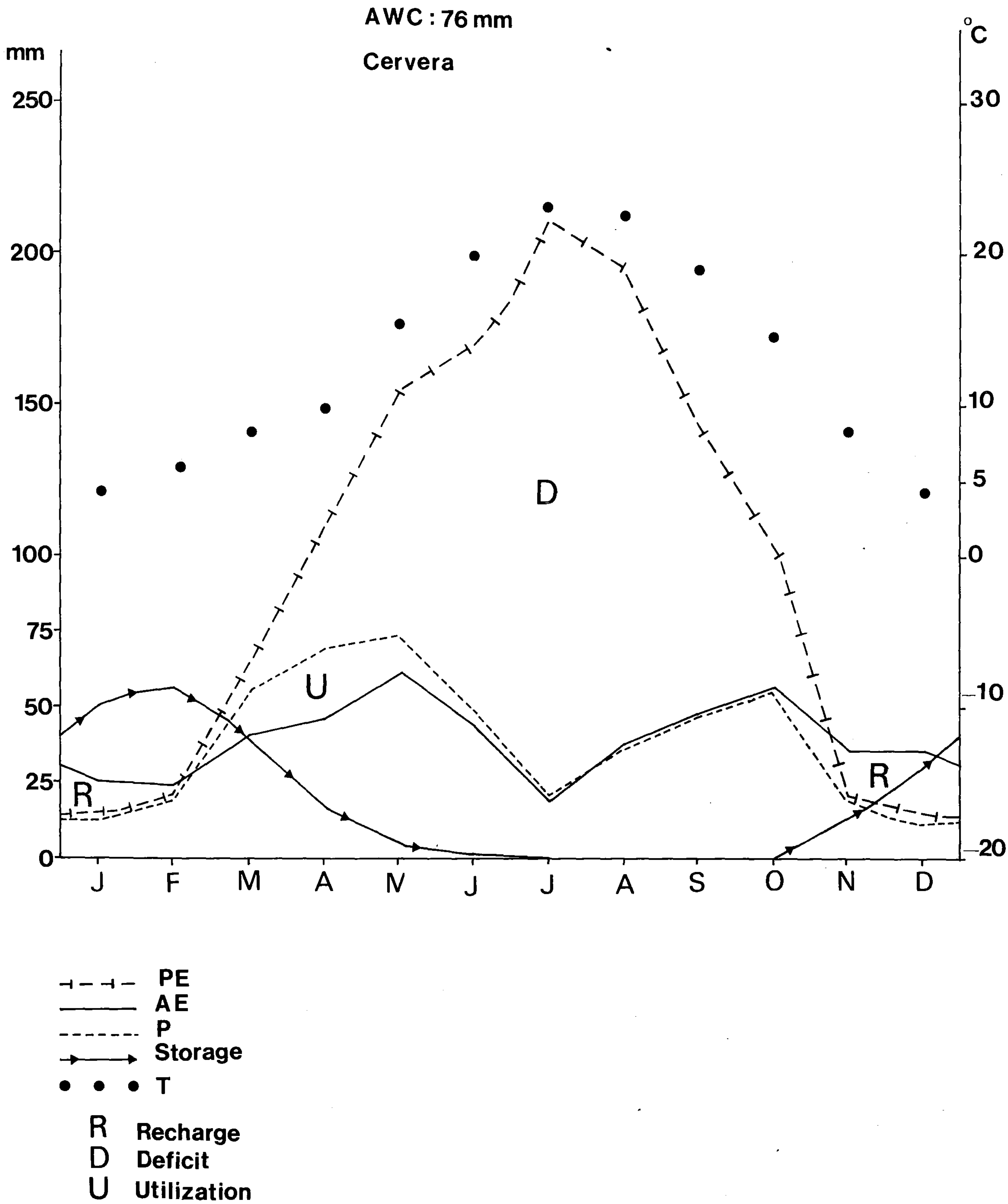


FIGURE 3-III Graphical representation of the water balance from Table 2-III.

APPENDIX IV

DESCRIPTION OF THE PLATES FROM THE THIN SECTIONS USED IN THE MICROMORPHOLOGY*

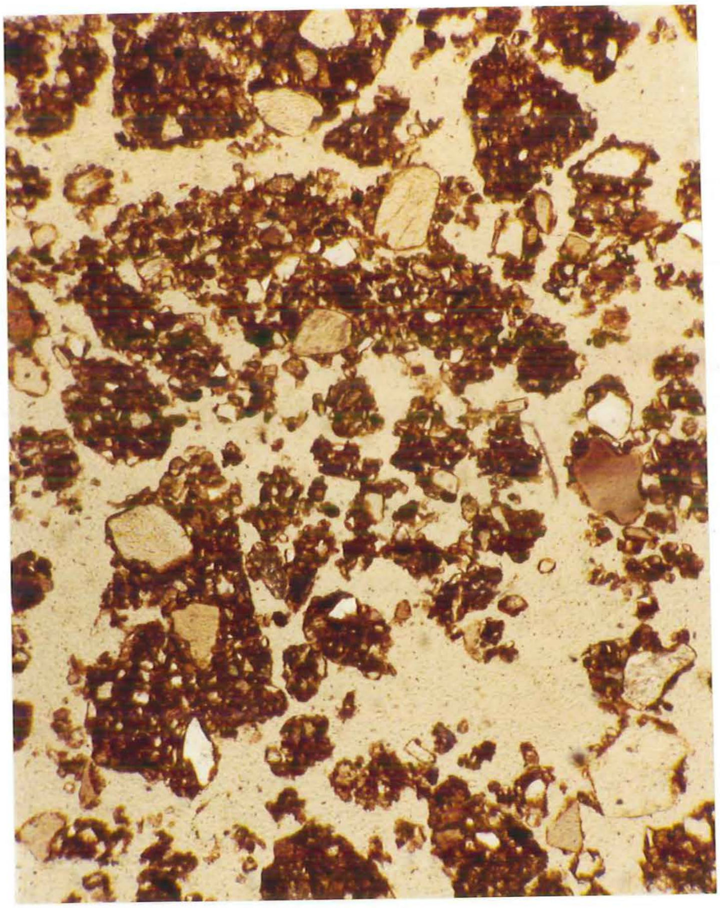


PLATE 1 Crumbly microstructure in the Ap horizon. Plain light, (x 25). Profile E-19.

* According to J. Boixadera.

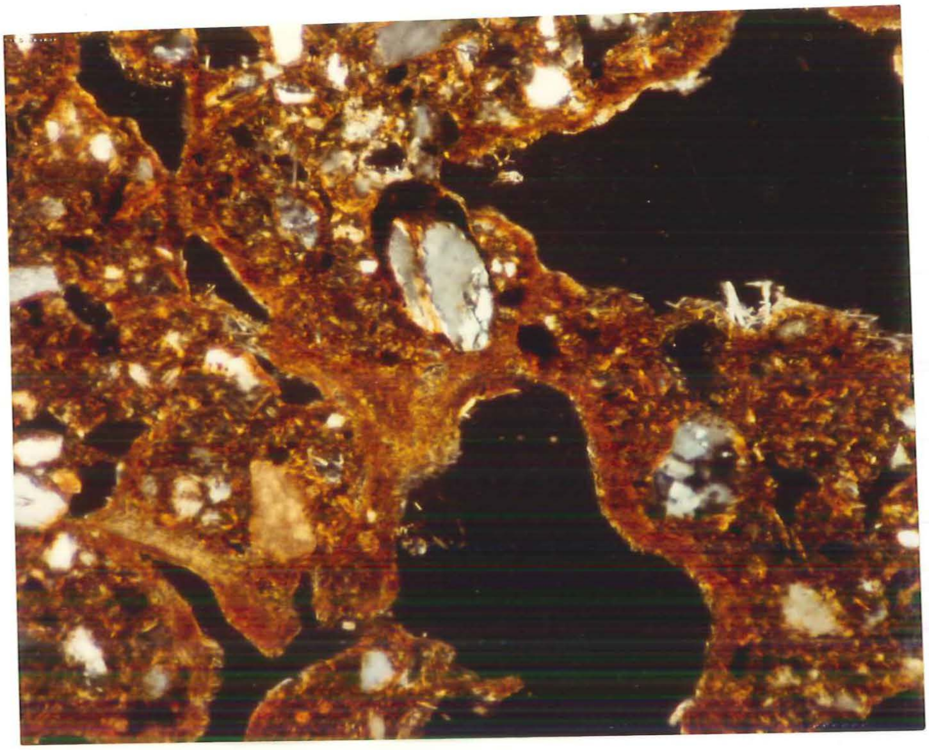


PLATE 2 Horizon Bwt1: thin argillans in the void walls. Lublinite occurs together with the argillans forming discontinuous lublinitans. (Crossed polarizers; x 100) Profile E-19.

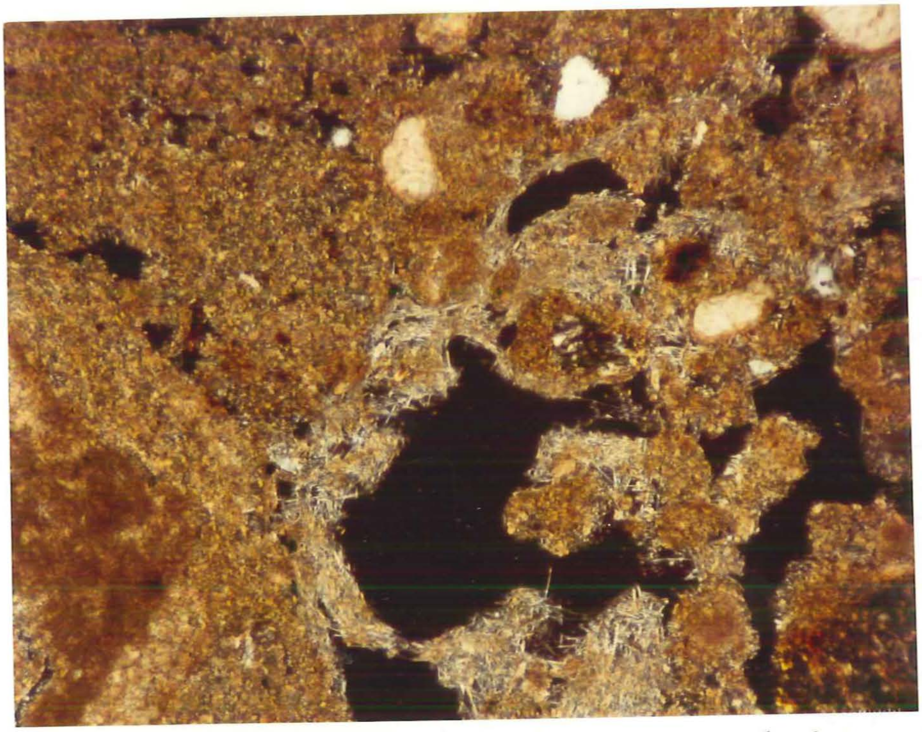


PLATE 3 Horizon 2Bwk1: generalized accumulation of carbonates. Nodular bodies, large crystals, micrite and lublinite are the forms shown. (Crossed polarizers; x 100) Profile E-19.

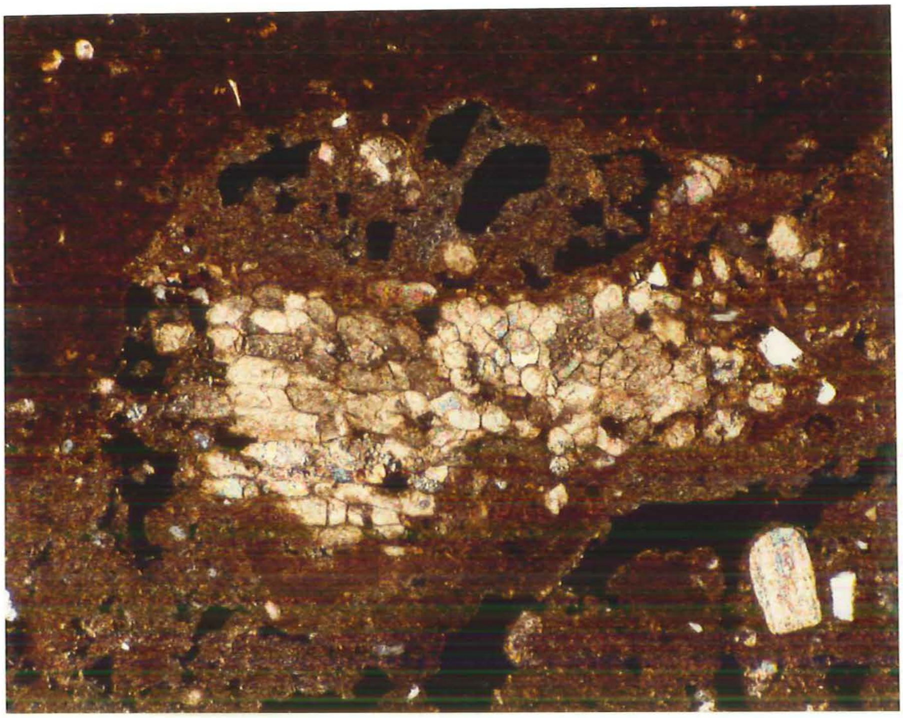


PLATE 4 Horizon 2Bwkl: pseudomorph with large calcite crystals. (Crossed polarizers; x 40)
Profile E-19.

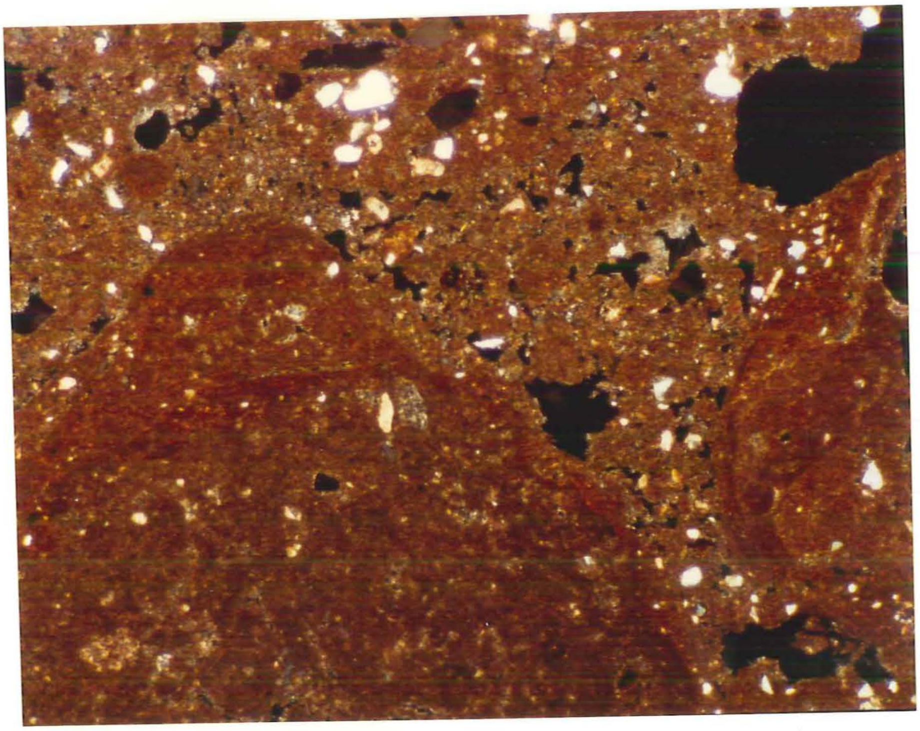


PLATE 5 Bw horizon: hypocoatings of iron and clay in nodules. (Crossed polarizers; x 25)
Profile E-20.

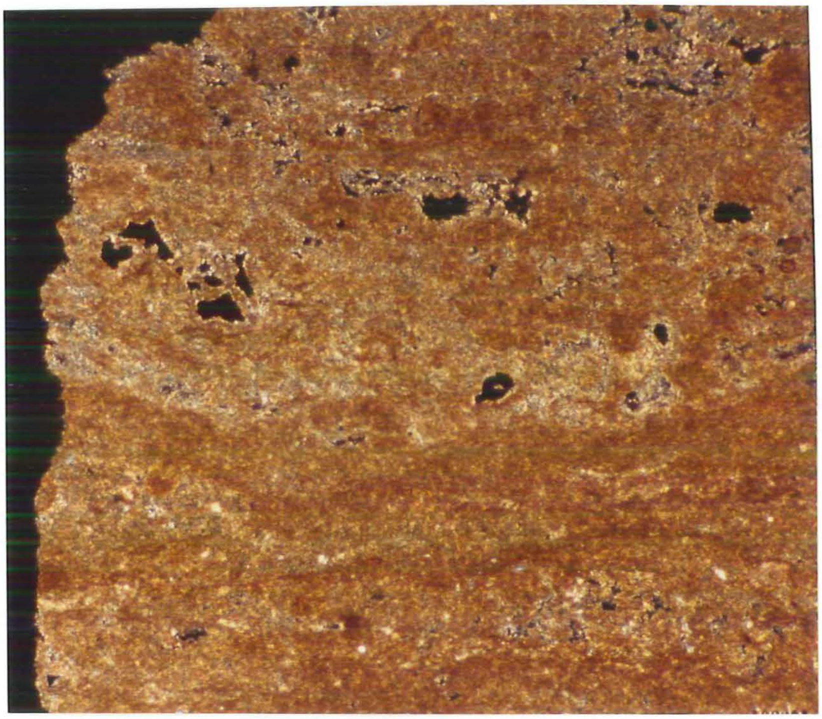


PLATE 6 Cmk2 horizon: fragment of cracked calciete, showing different density and compacity of the CaCO accumulation. (Crossed polarizers; x 25). Profile E-20.