INTERNATIONAL SYMPOSIUM ON SOILS WITH GYPSUM

Lleida, 15 - 21 september 1996

SOILS WITH GYPSUM OF THE CENTRAL CATALAN DEPRESSION

EXCURSION GUIDE

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1. INTRODUCTION

The Central Catalan Depression is the name given to the eastern sector of the Tertiary Ebro sedimentary basin.

The geological and climatic characteristics of this region along the Tertiary and Quaternary have been the origin of evaporite formations which are widespread in the Depression. They have given rise to a wide typology of soils with gypsum, mainly depending on the type of formation -marine or continental- and on geomorphological and climatic changes during the Quaternary. Agricultural landuse, which exists in this region since (pre)historical times, has also affected soil morphology.

The objective of this excursion is to visit several of these soils, located in the western sector of the Catalan Central Depression, in order to discuss their genesis, relation with the landscape and vegetation, landuse and classification.The itinerary of the excursion is displayed in Fig. 1.

The excursion is organized visiting three main areas:

- An area where gypsum rocks outrop under dryland conditions: **Ivorra site**, where the soil- landscape relationships will be discussed in depth.

- An area where gypsum soils occur in large alluvial fans under irrigation: **Urgell site**, where strong differences in soil morphology will be demonstrated.

- An area where gypsum soils occur in smaller alluvial fans linked to the Tertiary gypsum outcrops under dryland conditions: **Algerri site**, where gypsum accumulations are more indurated and occur in gravelly materials.

The methods for soil surveying and field description are based on C.B.D.S.A. (1983). The description and references for the physical and chemical analytical methods can be found in Porta et al. (1986) and in Porta et al. (1993). Some adaptations needed for gypseous materials are detailed in Herrero (1991) and Poch (1992). Thin sections are described according to Bullock et al. (1985), with adaptations and new terms introduced in Spanish by Herrero (1991) and in English by Herrero and Porta (1992) and Stoops & Poch (1994).
Regarding the specific terms applied to soils with gypsum, the reader can consult the short note by Herrero (1996) included in the Proceedings of the Symposium.

The excursion guide provides general information about the area, as well as detailed information of the sites visited.

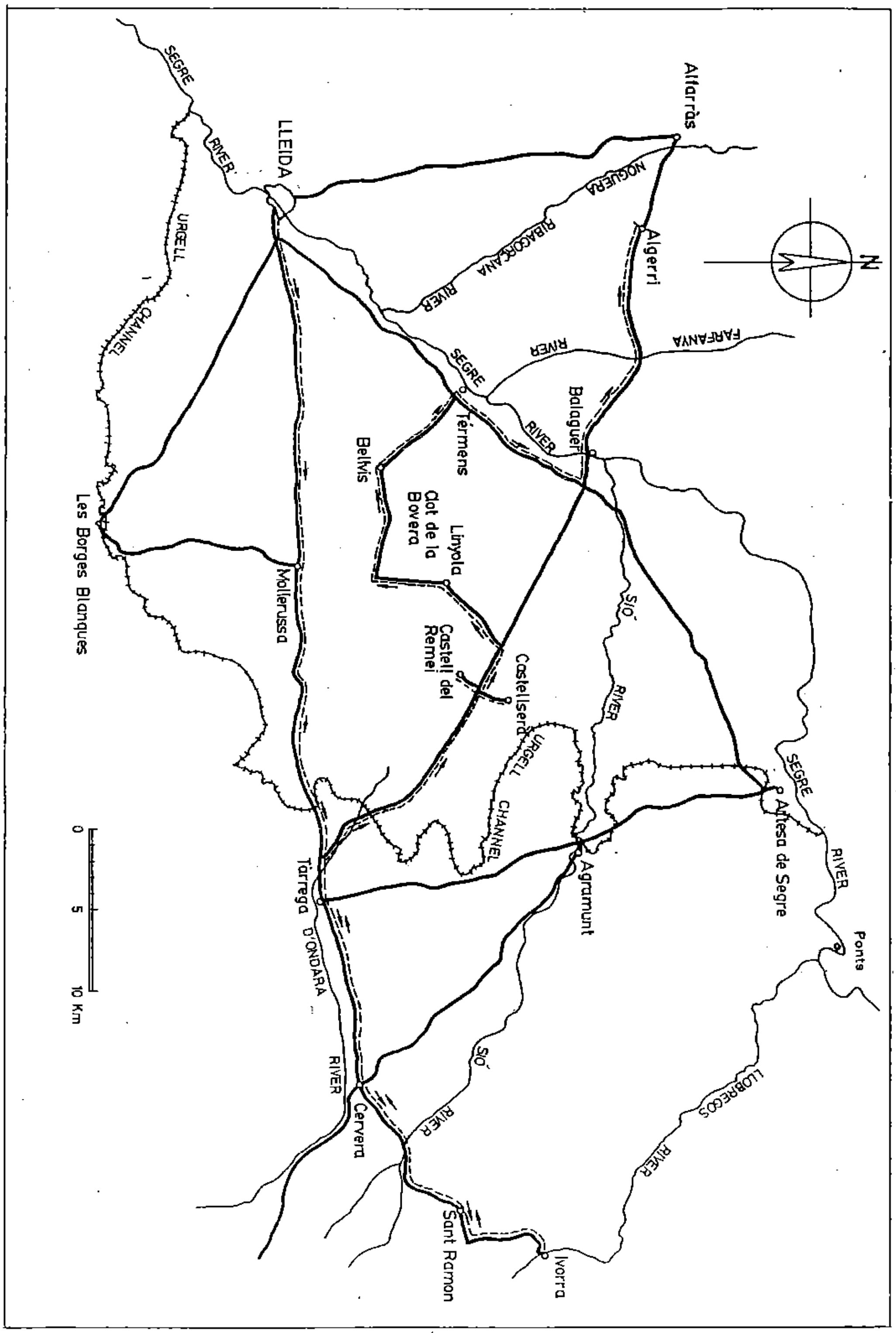


Figure 1 Itinerary of the excursion

2. ENVIRONMENTAL FACTORS IN THE CENTRAL CATALAN DEPRESSION

2.1. CLIMATE

The climatic characterization of the area has been done using the basic information of the Spanish National Meteorological Institute (I.N.M.). The meteorological stations which data has been used in this study and their localization are described in Table 1 and Figure 1. The basic data that has been used in this study is shown in Table 2.

Table 1. Location of the meteorological stations used for the climatic characterization of the area.

Meteorological station	Latitude (N)	Longitude (E)	Elevation (m)
Alfarràs	41° 50'	4° 15'	281
Balaguer	41° 48'	4° 30'	233
Lleida	41° 37'	4° 18'	221
Mollerussa	41° 38'	4° 35'	250
Ponts	41° 55'	4° 53'	362
Tàrrega	41° 39'	4° 50'	373

Table 2.- Length of the data period used in this climatic study for every meteorological station.

Meteorological station	Rainfall (R)	Temperature (T)	Potential evapotranspiration (PET) (Thornthwaite)	Reference evapotranspiration (ETo) (Blanney-Criddle/FAO)
Alfarràs	1973 - 1983	1972 - 1983	1974 - 1982	-
Balaguer	1951 - 1977	1951 - 1979	1954 - 1967	-
Lleida	1973 - 1983	1916 - 1991	1916 - 1991	-
Mollerussa	1917 - 1991	1961 - 1991	1962 - 1989	P (1917 - 1991), T (1961 - 1991)
Ponts	1941 - 1980	1963 - 1980	1963 - 1980	-
Tàrrega	1928 - 1991	1930 - 1991	1931 - 1981	-

From the Lleida meteorological station other meteorological data has been used:

- Bright sushine hours per day (1973 - 1988)
- Minimum daily relative humidity (1973 - 1988)
- Windspeed during day time (1973 - 1988)

2.1.1. RADIATION

The short wave solar radiation (Rs) are presented in Table 3. Rs has been calculated using the formula:

$$Rs = (a_s + b_s * n / N) * R_a$$

where:
a_s: 0.25
b_s: 0.50
n / N : relative sunshine fraction
Ra : extraterrestrial radation (MJ m^{-2} d^{-1})

Table 3. Short wave solar radiation (Rs) from Lleida station.

Month	J	F	M	A	My	J	Jl	Ag	S	O	N	D
n / N (%)	41.6	52.5	60.8	60.0	62.8	68.6	71.4	73.2	66.6	60.4	47.1	34.8
Rs (MJ m^{-2} d^{-1})	6.2	9.8	14.3	17.2	20.5	23.0	23.6	20.6	16.1	11.4	7.2	5.1

The low values of the relative sushine fraction during winter, especially in december, are related to thick persistent fog. The high radiation in summer months allows high yields of summer crops if water is not a limiting factor.

2.1.2. TEMPERATURES

The average montly temperatures from the different meteorological stations are shown in Table 4. The temperature map distribution of the Ebro Valley is shown in Figure 2.

Table 4. Average monthly temperature (T (°C)) from different meteorological stations.

	ALFARRÀS	BALAGUER	LLEIDA	MOLLERUSSA	PONTS	TÀRREGA
MONTH	T (°C)	T (°C)	T (°C)	T (°C)	T (°C)	T (°C)
January	4.9	5.4	5.0	4.0	4.1	3.6
February	6.7	7.5	7.3	6.0	6.1	5.8
March	8.4	11.1	10.6	9.0	8.8	9.4
April	10.8	13.9	13.2	11.6	11.8	12.3
May	14.8	18.4	17.1	15.9	16.3	16.2
June	18.9	22.4	21.3	20.4	20.1	20.7
July	23.0	25.4	24.4	23.6	23.0	24.0
August	22.0	24.3	23.9	23.0	22.1	23.5
September	19.1	21.3	20.8	19.8	18.9	19.9
October	14.1	16.1	15.4	14.6	13.6	14.2
November	8.5	9.9	9.6	8.0	7.8	8.2
December	5.2	6.1	5.8	4.5	4.3	4.5
Year	13.0	15.1	14.6	13.4	13.1	13.5

July is the month which has the highest average temperatures ranging from 23.0 °C to 25.4°C. The coldest month is January with an average temperature ranging from 3.6°C to 5.4 °C. The annual thermal oscillation is from 18.1 °C to 20.4 °C.

A wider temperature characterization is done for Mollerussa station and it is summarized in Table 5.

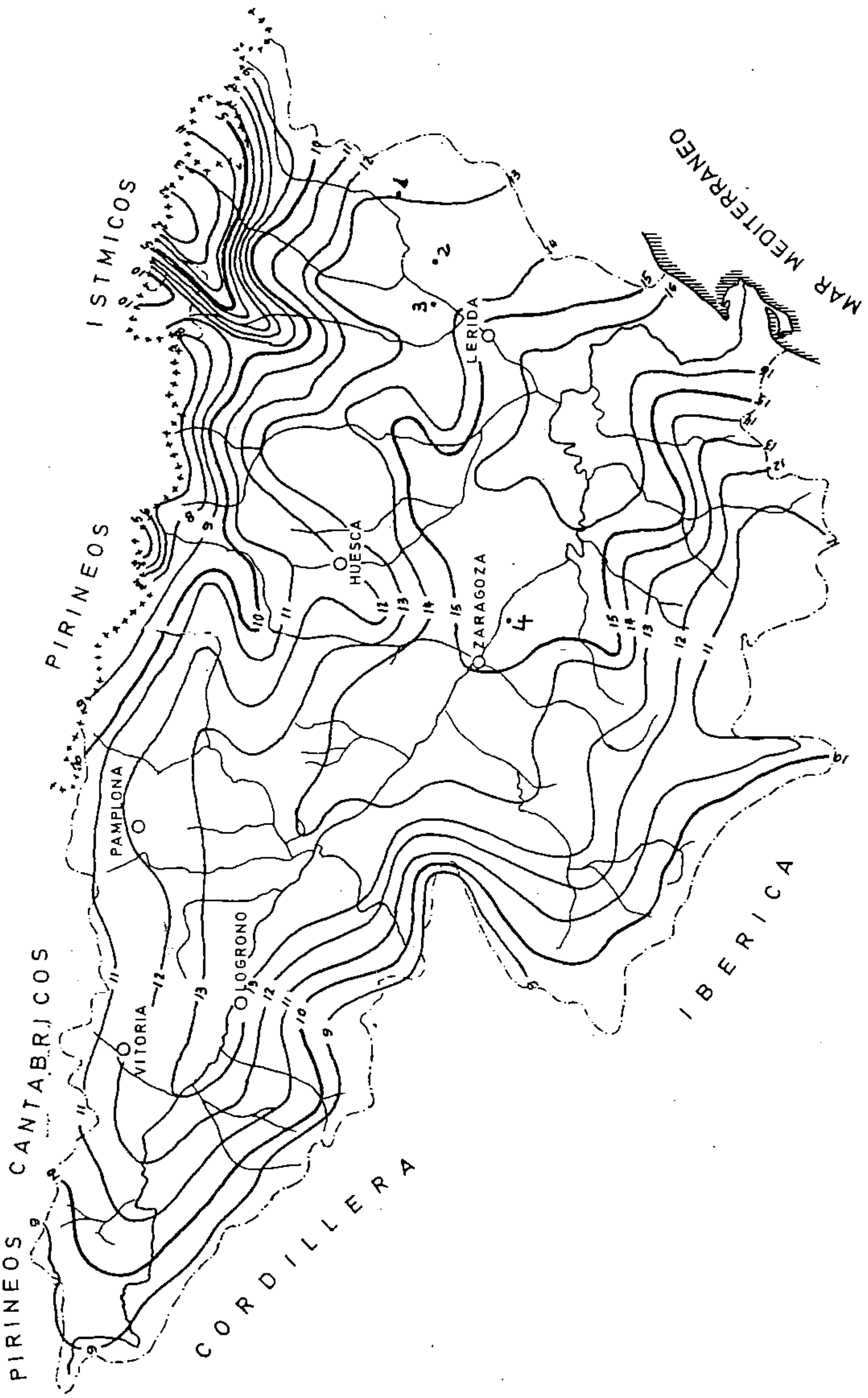


Figure 2 Temperature map distribution of the Ebro Valley. 1. Ivorra, 2. Castell del Remei, 3. Algerri, 4.Quinto. (Source: Biel et al., 1962)

Table 5.- Temperature regime from Mollerussa station (temperatures °C)

Month	Absolute minimum	Average of absolute minimum	Average of minimum	Average	Average of maximum	Average of absolute maximum	Absolute maximum	Average of day	Average of night
J	-19	-5.9	-0.8	3.7	8.6	15.5	21	6.2	1.6
F	-9	-4.4	0.2	6.0	11.8	17.7	22	8.9	3.1
M	-9	-3.3	2.5	9.0	15.5	22.4	27	12.2	5.7
A	-4	-1.3	4.8	11.6	18.4	25.0	30	15.0	8.2
My	0	3.8	8.8	15.9	23.1	29.6	35.5	19.5	12.3
J	3	7.8	12.8	20.4	27.9	34.4	40	24.1	16.6
Jl	7	11.6	15.6	23.6	31.7	37.2	43	27.8	19.6
Ag	7	10.6	15.5	23.0	30.6	36.1	42	26.8	19.3
S	3	7.5	12.8	19.8	26.8	32.0	39	23.3	16.3
O	-3	2.8	8.3	14.6	20.8	27.0	32	17.7	11.5
N	-8	-3.6	2.8	8.0	13.2	20.3	26	10.6	5.4
D	-16	-4.14	0.1	4.5	8.9	15.2	20	6.7	2.3

The length of cold period, using Emberger criteria (period where the average of minimum temperatures is less than 7 °C), is from November to April.

The length of hot period (period whose average of maximum temperatures is more than 30°C) includes July and August.

The frost risk using Papadakis and Emberger criterion is summarized in Table 6.

Table 6. Periods of frost risk using Papadakis and Emberger criterion for Mollerussa.

EMBERGER criterion			PAPADAKIS criterion		
Risk of frost	**Average minimum temperature**	**Period length**	**Risk of frost**	**Average absolute minimum temperature**	**Period length**
Total	< 0 °C	Dec, Jan, Feb	Average period	< 0 °C	Nov. to April
Frequent	0 - 3 °C	Nov, March	Average free period	0 - 2 °C	October
Slightly	3 - 7 °C	April	Possible free period	2 - 7 °C	May
Un-frequent (< 20%)	> 7 °C	May to October	Free period	> 7 °C	June to Sept.

2.1.3. RAINFALL

The annual rainfall distribution has its maximum during the spring (31% of the annual rainfall) and in autumn (32% of the annual rainfall). The summer rainfall presents a high irregularity and it is linked to heavy rainstorms.

The average annual rainfall ranges from 368 to 557 mm. The maximum monthly rainfall happens in May (49-70 mm) and September (36-60 mm). The minimum monthly rainfall happens in July (14-22 mm) and February (18-21 mm), except for Ponts station, where it is in January (29 mm). The average monthly rainfall for the different sites are presented in Table 7.The rainfall distribution map of the Ebro Valley is shown in Figure 3.

The average effective rainfall for Mollerussa station has been calculated using a net depth of irrigation of 65 mm and the values of the evapotranspiration of the reference crop (ETo). Its values are presented in Table 7.

Table 7 Average montly rainfall (R(mm)) for the different meteorological stations and the effective precipitation (ER(mm)) for Mollerussa station.

	ALFARRÀS	**BALAGUER**	**LLEIDA**	**MOLLERUSSA**	**PONTS**	**TÀRREGA**	**MOLLERUSSA**
Month	R (mm)	R (mm)	R (mm)	R (mm)	R (mm)	R (mm)	ER (mm)
January	30.9	22.4	21.3	18.9	28.8	27.3	10.8
February	19.1	23.9	18.4	19.9	40.0	21.0	11.5
March	32.8	33.9	29.2	31.8	37.4	33.2	18.2
April	50.9	36.5	37.8	36.4	62.7	41.3	20.8
May	61.0	55.5	48.7	49.8	70.3	52.2	27.8
June	33.8	44.6	39.0	32.7	56.7	40.2	18.8
July	17.3	14.2	16.1	14.8	22.0	22.3	8.5
August	42.1	30.9	26.4	24.3	50.8	31.5	14.1
Sept.	50.9	40.5	35.9	41.9	60.5	46.1	23.7
October	38.1	40.6	37.2	44.9	55.6	40.1	25.1
Nov	32.3	31.2	30.7	36.3	36.0	31.2	20.6
Dec.	29.1	32.5	27.1	28.6	36.6	33.8	16.4
Year	438.2	406.8	367.7	380.4	557.0	420.2	-

The Gumbel distribution has been used in order to calculate the return period for maximum rainfall for 24 hours. The results for Mollerussa meteorological station are presented in Table 8.The maximum rainfall for 24 hours period in two years could be higher than 39.8 mm and for a period of 10 years the maximum rainfall could be higher than the average May monthly rainfall.

Table 8. Return periods for a maximum rainfall for 24 hours period -Mollerussa station-

Return Period (years)	**Maximum rainfall for 24 hours period (mm)**
2	39.8
5	52.2
10	60.4
20	68.3
25	70.8
50	78.5
100	86.1

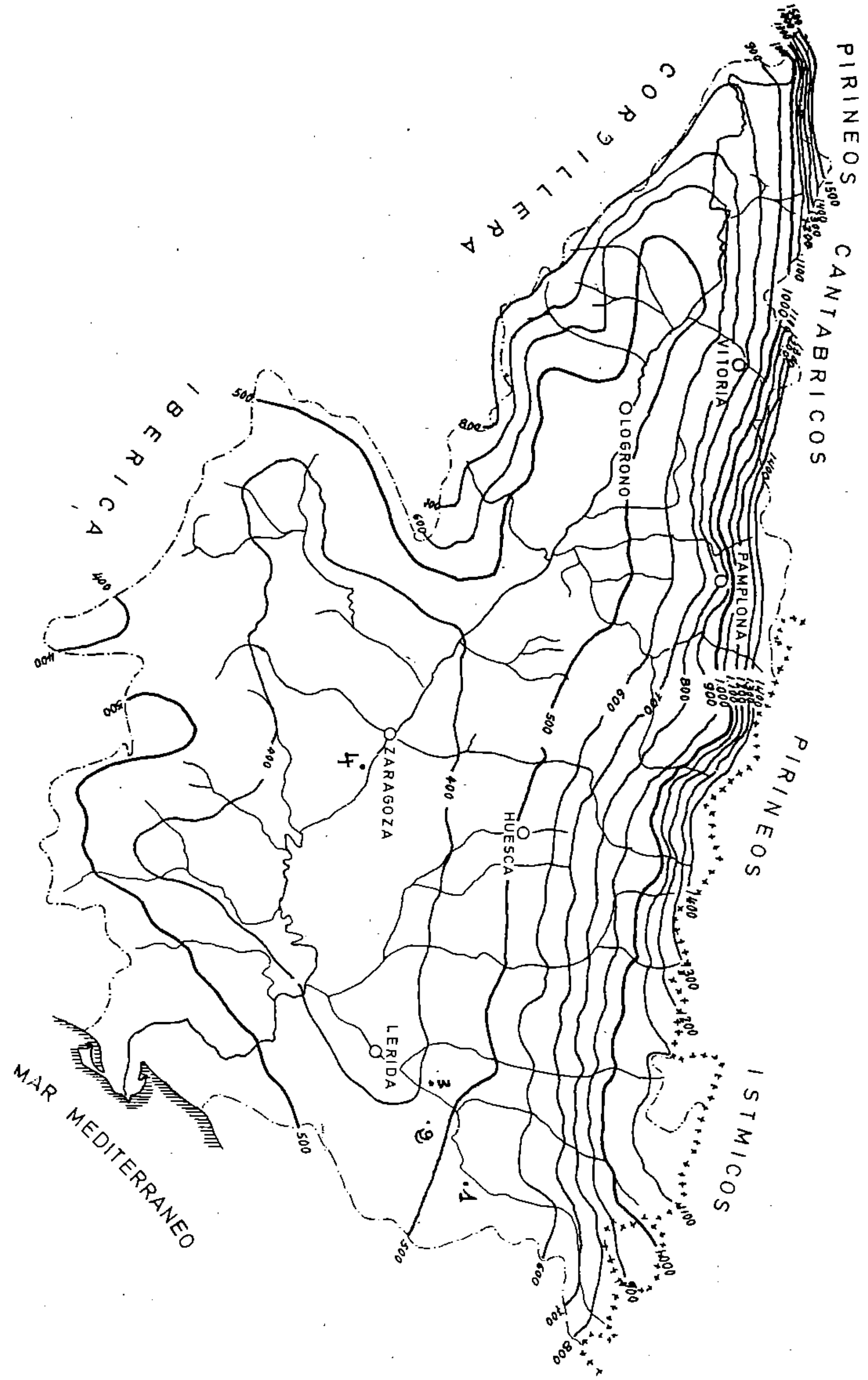


Figure 3 Rainfall distribution map of the Ebro Valley. 1. Ivorra, 2. Castell del Remei, 3. Algerri, 4. Quinto. (Source: Biel et al., 1962).

2.1.4. POTENTIAL EVAPOTRANSPIRATION, CROP WATER NEEDS AND WATER BALANCE

The potential evapotranspiration has been calculated for every meteorological station using Thornthwaite formula. The results are presented in Table 9. July has the maximum evapotranspiration, the daily PET ranges from 4.6 mm d^{-1} to 5.1 mm d^{-1}.

Table 9. Potential evapotranspiration (PET, mm) using Thornthwaite formula.

	ALFARRÀS	BALAGUER	LLEIDA	MOLLERUSSA	PONTS	TÀRREGA
Period	(1974-1982)	(1954-1967)	(1916-1991)	(1962-1989)	(1962-1989)	(1931-1981)
Month						
January	11.1	8.3	9.1	8.6	8.4	7.2
February	18.0	15.1	16.2	13.8	14.8	12.9
March	28.6	36.8	34.9	30.3	30.5	30.9
April	43.2	50.2	52.0	47.6	49.1	50.0
May	75.9	94.9	87.9	82.0	86.5	84.7
June	108.5	124.8	122.1	117.8	117.0	119.8
July	142.2	158.8	153.0	147.1	142.6	149.6
August	122.9	140.1	138.1	131.8	125.4	135.5
September	89.1	107.5	98.7	92.8	88.0	94.4
October	56.0	59.8	56.3	56.2	51.2	52.6
November	23.7	21.7	23.7	21.4	20.4	20.2
December	12.3	9.7	11.5	8.6	8.6	9.0
Year	731.3	827.7	803.4	757.9	742.5	766.8

The reference crop evapotranspiration (ETo) has been calculated from Mollerussa station using Blanney-Criddle (modified by FAO) formula. The data of windspeed, relative humidity and bright sunshine hours per day have been taken from Lleida meteorological station because of the lack of this information in Mollerussa. The results are shown in Table 10. In this case, the values of potential evapotranspiration are higher than using Thornthwaite potential evapotranspiration. In July the difference is about 1.7 mm d^{-1} for Mollerussa station.

The water balance has been done for Tàrrega and Mollerussa stations using the values of PET and rainfall for the same period of time. The available water holding capacity is assumed to be 100 mm. The results are shown in Tables 11 and 12. The annual deficits are 337.8 mm for Tàrrega and 380.3 mm for Mollerussa station. The dry period starts on April and lasts until October.

Another water balance using Mollerussa station data has been calculated using the efective rainfall and the ET_0 previously calculated. The results are shown in Table 13. In this case the annual deficit exceeds 885.7 mm and all the months are dry except December and January.

Table 10. Reference crop evapotranspiration (ETo, Blanney-Criddle, modified by FAO) for Mollerussa meteorological station.

Month	T (°C)	P (%)	n/N -	RHmin (%)	U (km/h)	U (m/s)	Ud (m/s)	Ud2m (m/s)	f (mm/d)	ETo (mm/d)
J	4.0	0.22	0.42	71.8	7.3	2.0	2.7	1.9	2.2	0.3
F	6.0	0.24	0.52	58.8	9.3	2.6	3.4	2.5	2.6	1.0
M	9.0	0.27	0.61	47.1	11.2	3.1	4.1	3.0	3.3	2.2
Ap	11.6	0.30	0.60	44.3	11.1	3.1	4.1	3.0	4.0	3.1
My	15.9	0.32	0.63	43.9	10.3	2.9	3.8	2.7	4.9	4.3
Ju	20.4	0.34	0.69	41.6	10.3	2.9	3.8	2.7	5.9	5.8
Jl	23.7	0.33	0.71	38.3	8.9	2.5	3.3	2.4	6.3	6.5
A	23.0	0.31	0.73	42.3	8.7	2.4	3.2	2.3	5.8	5.7
S	19.8	0.28	0.67	47.1	7	1.9	2.6	1.9	4.8	3.9
O	14.6	0.25	0.60	54.4	7.7	2.1	2.9	2.1	3.7	2.3
N	8.0	0.22	0.47	64.1	7.2	2.0	2.7	1.9	2.6	0.8
D	4.5	0.21	0.35	74.3	6.4	1.8	2.4	1.7	2.1	0.2

T : average monthly temperature, U: wind speed, P: daily percentage of annual day hours, Ud: day wind speed, n/N: relative sunshine fraction, Ud2m: day wind speed at 2 m height, RHmin: minimum relative humidity, f: non-corrected ETo values.

Table 11. Water balance using Tàrrega station data.

MONTH	R (mm)	PET (mm)	R-PET	apl (mm)	SM (mm)	SMV	AET	D	S	R
J	23.6	7.2	16.4	0	56.9	16.4	7.2	0	0	0
F	20.8	12.9	7.9	0	64.8	7.9	12.9	0	0	0
M	35.3	30.9	4.4	-36.8	69.2	4.4	30.9	0	0	0
A	41.2	50.0	-8.8	-45.6	63.4	-5.8	47.0	3.0	0	0
My	50.1	84.7	-34.6	-80.2	44.8	-18.5	68.6	16.1	0	0
J	44.2	119.8	-75.6	-155.8	21.1	-23.8	68.0	51.8	0	0
Jl	23.5	149.6	-126.1	-281.9	6.0	-15.1	38.6	111.0	0	0
Ag	32.0	135.5	-103.5	-385.4	2.1	-3.8	35.8	99.7	0	0
S	49.6	94.4	-44.8	-430.2	1.4	-0.8	50.4	44.0	0	0
O	40.2	52.6	-12.4	-442.6	1.2	-0.2	40.4	12.2	0	0
N	30.8	20.2	10.6	0	11.8	10.6	20.2	0	0	0
D	37.7	9.0	28.7	0	40.5	28.7	9.0	0	0	0
Year	429.0	766.8	-337.8				429.0	337.8		

PET: potential evapotranspiration, AET: actual evapotranspiration, R: rainfall, D: deficit, apl: acumulated potential losses, S: surplus, SM: soil moisture, P: percolation, SMV: soil moisture variation.

Table 12. Water balance using Mollerussa station data.

MONTH	R (mm)	PET (mm)	R-PET	apl (mm)	SM (mm)	SMV	AET	D	S	R
J	21.4	8.6	12.8	0	42.4	12.8	8.6	0	0	0
F	22.6	13.8	8.8	-66.9	51.2	8.8	13.8	0	0	0
M	29.2	30.3	-1.1	-68.0	50.7	-0.5	29.7	0.6	0	0
A	38.4	47.6	-9.2	-77.2	46.2	-4.4	42.8	4.8	0	0
My	46.8	82.0	-35.2	-112.4	32.5	-13.7	60.5	21.5	0	0
J	34.6	117.8	-83.2	-195.6	14.1	-18.4	53.0	64.8	0	0
Jl	10.9	147.1	-136.2	-331.8	3.6	-10.5	21.4	125.7	0	0
Ag	29.9	131.8	-101.8	-433.7	1.3	-2.3	32.2	99.6	0	0
S	41.4	92.8	-51.4	-485.1	0.8	-0.5	41.9	50.9	0	0
O	43.5	56.2	-12.6	-497.7	0.7	-0.1	43.6	12.6	0	0
N	34.0	21.4	12.5	0	13.2	12.5	21.4	0	0	0
D	24.9	8.6	16.3	0	29.6	16.3	8.6	0	0	0
Year	377.6	758.0	-380.4				377.5	380.5		

Table 13.- Water balance for Mollerussa meteorological station.

MONTH	ER (mm)	ETo (mm)	ER-ETo	apl (mm)	SM (mm)	SMV	AET	D	S	R
J	10.8	9.6	1.2	-218.9	11.2	1.2	9.6	0	0	0
F	11.5	27.8	-16.3	-235.2	9.5	-1.7	13.2	14.7	0	0
M	18.2	67.3	-49.1	-284.3	5.8	-3.7	21.9	45.4	0	0
A	20.8	93.5	-72.7	-357.1	2.8	-3.0	23.8	69.7	0	0
My	27.8	132.1	-104.3	-461.4	1.0	-1.8	29.6	102.5	0	0
J	18.8	175.0	-156.2	-617.5	0.2	-0.8	19.6	155.4	0	0
Jl	8.5	200.2	-191.7	-809.3	0	-0.2	8.6	191.6	0	0
Ag	14.1	176.0	-161.9	-971.2	0	0	14.1	161.9	0	0
S	23.7	118.0	-94.3	-1065.5	0	0	23.7	94.3	0	0
O	25.2	71.6	-46.4	-1111.9	0	0	25.2	46.4	0	0
N	20.6	24.4	-3.8	-1115.7	0	0	20.6	3.8	0	0
D	16.4	6.5	9.9	0	9.9	9.9	6.5	0	0	0
Year		1102.0						885.7		

2.1.5. CLIMATIC CLASSIFICATION AND AGRICULTURAL PRODUCTIVITY INDICES

The climatic type has been defined using Papadakis criterion. The classification are shown in Table 14. The area is included in the dry mediterranean zone, the temperature regime is in between the hot temperate to hot continental.

The Turc index has been used for evaluating the agricultural potential productivity of the area. The index is the product of an heliotermic factor and an aridity factor. The values of the index are summarized in Table 15. From April to October the productivity is linked to the availability of water, therefore irrigation is necessary for agricultural high productivity. During the winter period the productivity is limited by the low temperatures.

Table 14. Papadakis climatic classification from different meteorological stations.

	ALFARRÀS	BALAGUER	LLEIDA	MOLLERUSSA	PONTS	TÀRREGA
Winter type	av	av	av	av	av/Tv	av
Summer type	0	0	0	0	0	0
Temperature regime	CO/TE	CO/TE	CO/TE	CO/TE	CO	CO/TE
Hydric regime	Me *	Me *	Me *	Me	Me*	Me *
Percolation	54.0	61.5	43.5	84.7	132.4	54.2
Annual index of humidity	0.44	0.45	0.40	0.50	0.71	0.46
Climatic type	Temp. cont. Medi-terranean	Temp. cont. Medi-terranean	Temp. cont. Medi-terranean	Temp. cont. Mediterranean	Cont. Medi-terranean	Temp. cont. Medi-terranean

* All the conditions for the Mediterranean hidric regime are not fulfilled.

2.1.6. SOIL TEMPERATURE AND MOISTURE REGIMES

There is a lack of enough direct measures of the soil temperature and moisture regimes in the area. They are estimated from meterological data, at it is suggested by SSS (1975). The moisture regime for most of the area should be considered xeric. Jarauta (1989) measured during several years the soil water status in several points of the dryest part of the area (xeric-aridic limit), and proposed a modification of Newhall's model to estimate the soil moisture regime. According his data for this part of the area, soils with an AWHC (available water holding capacity) smaller of 50 mm should be considered with an aridic moisture regime, having the other soils a xeric moisture regime.

The soil temperature regime estimated from air temperature is mesic for the higher areas, and thermic for the lower parts closer to the Segre river.

Table 15.- Monthly Turc index for the agricultural productivity in dry (D) and irrigated (I) areas from different meteorological stations.

Month	Area	ALFARRÀS	BALAGUER	LLEIDA	MOLLERUSSA	PONTS	TÀRREGA
January	D	0.0	0.0	0.0	0.0	0.0	0.0
	I	0.0	0.0	0.0	0.0	0.0	0.0
February	D	0.1	0.1	0.3	0.0	0.4	0.0
	I	0.1	0.1	0.3	0.0	0.4	0.0
March	D	2.3	2.5	1.4	0.8	1.9	1.8
	I	2.4	3.0	2.8	0.8	1.9	1.8
April	D	2.1	1.6	1.9	2.0	4.1	2.8
	I	4.4	4.7	4.7	3.7	4.1	4.3
May	D	2.0	2.0	1.3	1.8	4.8	2.1
	I	5.8	6.4	6.3	5.9	6.0	6.0
June	D	0.0	0.0	0.1	0.0	1.2	0.0
	I	7.4	7.5	7.5	7.3	7.3	7.4
July	D	0.0	0.0	0.0	0.0	0.0	0.0
	I	7.6	7.7	7.7	7.5	7.5	7.6
August	D	0.0	0.0	0.0	0.0	0.0	0.0
	I	6.6	6.7	6.7	6.5	6.5	6.6
Septem-ber	D	0.0	0.0	0.0	0.0	2.1	0.0
	I	5.1	5.2	5.3	5.1	5.0	5.1
October	D	1.4	1.3	0.7	1.2	2.8	2.0
	I	3.0	3.2	3.1	3.0	2.9	2.9
Novem-ber	D	0.7	0.9	0.6	0.3	0.7	0.6
	I	0.8	0.9	0.8	0.3	0.7	0.6
Decem-ber	D	0.0	0.0	0.0	0.0	0.0	0.0
	I	0.0	0.0	0.0	0.0	0.0	0.0
Year	D	8.6	8.4	6.3	6.1	18.0	9.3
	I	43.3	45.5	45.1	40.1	92.3	42.3

2.2 GEOLOGY AND GEOMORPHOLOGY

The Central Catalan Depression is the name given to the eastern (catalan) sector of the Tertiary Ebro sedimentary Basin. The collision between the European Plate and Iberian Subplate since late Cretaceous to middle Miocene originated the Pyrenees (W-E), the Iberian (NW-SE) and the Catalan Coastal Ranges (SW-NE), which are alpine folding chains. The Ebro Basin remained as a roughly triangular shaped undeformed area between these chains, acting basically as the Pyrenees foreland basin (Fig. 4). The basin sedimentary depth increases south to north because of the subduction of the Iberian Plate, which originates strong subsidence values, reaching 3800 m in the catalan sector. A successive development of pyrenean thrusts, directed southwards, caused a southwestern displacement of the sedimentation axis, and also the foreland overlapping and folding in a fringe along the southern border of the chain, which reduced the basin extent.

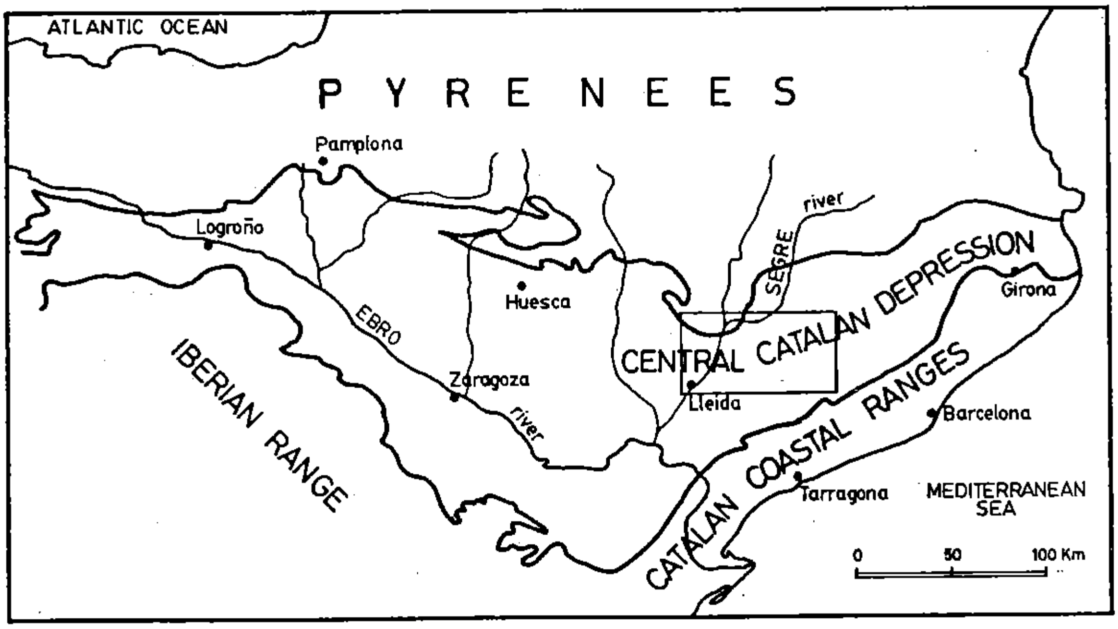


Figure 4. Location of the Central Catalan Depression within the Ebro Sedimentary Basin. The wes tern sector is nowadays drained by the Segre River across the Ebro River. Other rivers drain the Eastern sector directly to the Mediterranean Sea.

The basin was open to the Atlantic Ocean and closed to the Mediterranean-Thetys Sea by the Corsica-Sardinia and Balearic micro-plates. Late Cretaceous and Paleocene marine and continental formations, previous to the chain emergency, reflect this paleogeographic setting. After the first emergency of the proto-Pyrenees, two marine transgressions took place during Eocene, reaching the Ebro Basin catalan sector in the Ilerdian (Early Eocene, name taken from the ancient name of Lleida: Ilerda) and early Bartonian-Priabonian (Middle and upper Eocene) (Fig. 5).

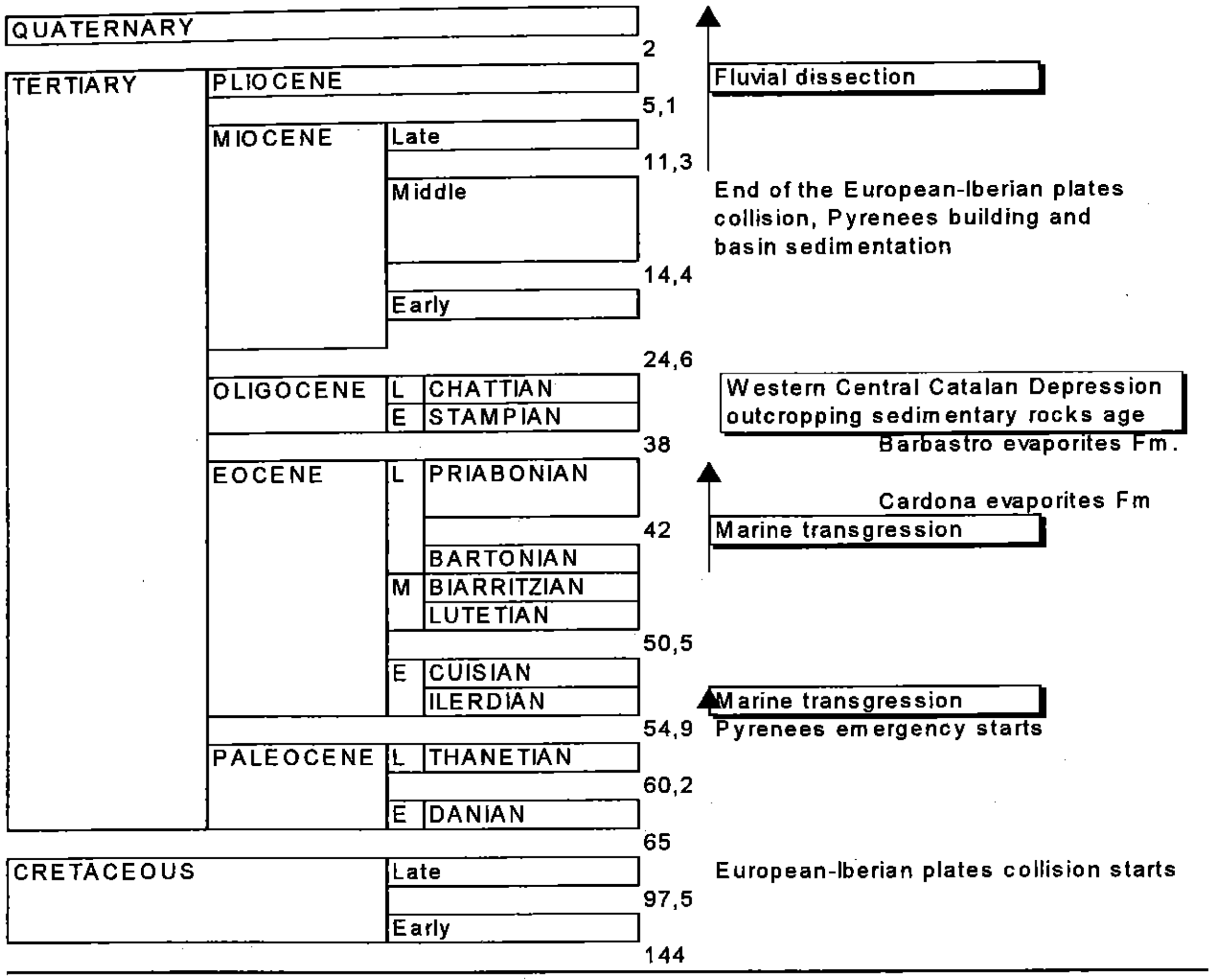


Figure 5. Western Central Catalan Depression geological time chart for events related to gypsum deposition. Ages in million years before present.

These marine transgressions and subsequent regressions left evaporite formations, at three levels into sedimentary series located successively from NE to SW, namely:

- *Beuda Formation.* Lutetian. It outcrops directly in Eastern Catalonia.

- *Cardona Formation.* Early Priabonian. It is an evaporitic sequence 300 m thick, most of it saline. It outcrops directly in the southern basin fringe but mainly in the folded foreland anticlinal cores directed SW-NE. These anticlines are often diapyric and are still active. The so named "Salt Mountain" in Cardona is exploited since Neolithic times and its surroundings are a center of an intensive potash salt mining.

- *Barbastro Formation.* Late Eocene-Early Oligocene. It consists of a continental evaporitic sequence 1000 m thick. It outcrops only in the 140 Km long Barbastro-Balaguer diapiric anticline, directed W-E. In this region the folded foreland is reduced to this single anticline, almost overlapped by a pyrenean thrust. It branches in two at its east end. The named Sanaüja anticline -where the Ivorra field trip site is located- is the northern branch, that connects with the Cardona

formation and borders its sedimentation basin.
During Oligocene and up to middle Miocene, when the building-up of the Pyrenees finished and the Mediterranean fluvial net captured the drainage basin, the sedimentation was entirely continental. The Oligocene sedimentary sequence of the Central Catalan Depression consists of conglomerates, sandstones and lutite *alluvial systems* with a source area in the Pyrenees and Coastal Ranges, merging laterally to *lacustrine systems* towards the basin axis. Sandstones, mudstones, marls, limestones, evaporites and local complex coal interbeddings built five lacustrine systems, that form a continuous outcrop along the basin axis. Gypsum is found in both sedimentary systems, as ephemeral lake sediments in the lutitic alluvial plains or as playa or playa-lake sediments among lacustrine ones. Oligocene materials outcrop normally in the western area of the Central Catalan Depression.

The climate, uniformly warm -tropical or subtropical- during Tertiary , helped evaporite formation. After middle Miocene, the Ebro and other Mediterranean rivers strongly dissected the Ebro tertiary Basin sedimentary fill. Different stages during the general dissection process have left a number of fluvial terraces and other perched alluvial fills, some of them more than 100 m high over the present alluvial plain.

Lithologic, structural, dynamic and climatic factors control the Central Catalan Depression landforms (Fig. 6). In a basically flat bedding region, the main features of the landscape reflect the facies distribution. In this way, the most depressed area -Urgell Plain- lies over the Urgell formation, a lutitic Oligocene distal plain. It is partially covered by recent alluvial sediments and is surrounded by higher structural landscapes over materials more resistent to erosion, which are the following:

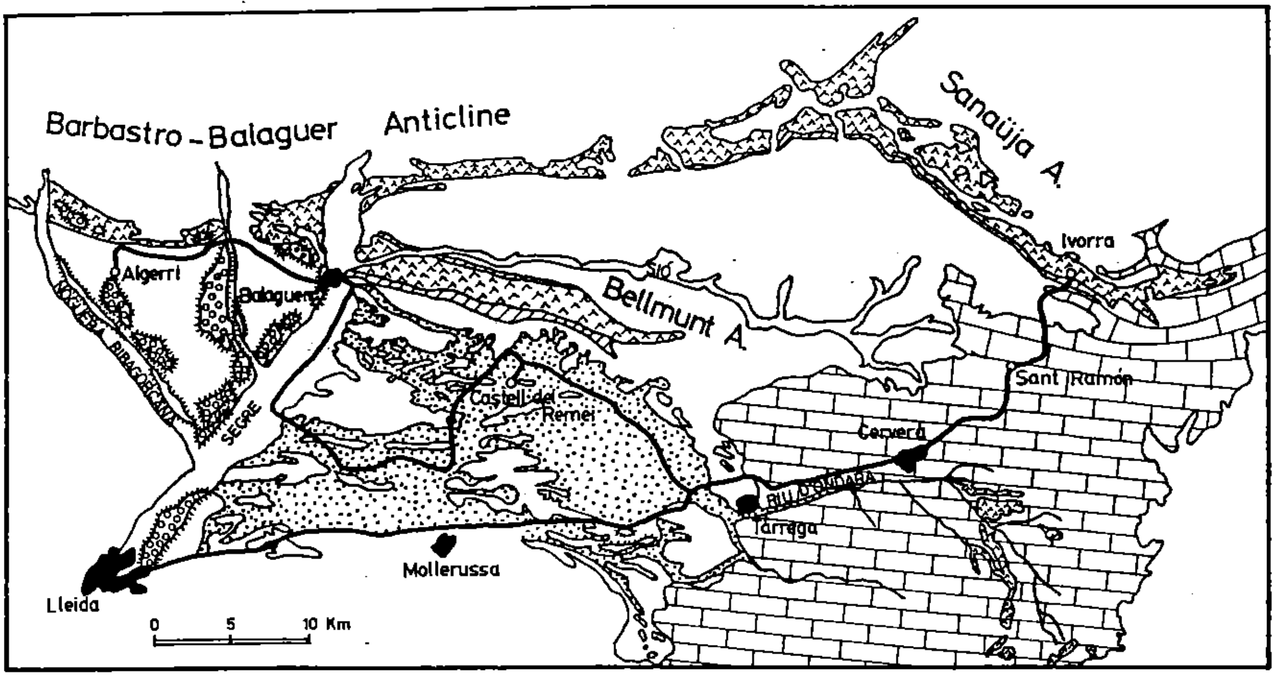
- Tabular landscape -Garrigues- over lacustrine limestones and alluvial sandstones of the Oligocene sedimentary axis, to the South.

- Cuestaform landscape -Segarra or Central Altiplane- to the East, over the same limestone and sandstone formations with a slight sedimentary or tectonic dip facing the central plain. The so named "Costes de Vicfred" scarp, close to the first field trip site, is a cuesta front in the southern side of the Sanaüja anticline.

- Flatiron landscape to the North, on the overstepped sandstone and limestone beds at the diapyric anticline sides. Along the fold axes of the anticlinal, perched valleys develop over gypsum outcrops. The erosion by gypsum dissolution is continuously balanced by a diapyric uplift causing neotectonic features, like the deformed quaternary terraces found near Balaguer.

- Tabular landscape to the West, over encrusted gravel Segre river terraces. It merges directly to the Garrigues tabular landscape, and through the Urgell plain by scattered old alluvial fills, perched over the plain bottom.

Different depositional forms are related to the dissection dynamics that has been lowering the baselevel since the end of the basin fill. These forms are the fluvial terraces of the Segre and other pyrenean rivers, and the alluvial sheet fills with source areas located in the near Catalan Central Depression or Coastal Ranges highlands. The highest and oldest (Pliocene) pyrenean fluvial fills have also a sheet piedmont depositional geometry.



Old dissected alluvial fills.

Recent or present-day alluvial fills. Alluvial fans of the d'Ondara and other rivers

Oligocene lacustrine complex: marl, limestone and gypsum. D'Ondara river source area.

Eocene Barbastro gypsum outcrops. Barbastro-Balaguer, Bellmunt and Sanaüja anticlines and southern non-folded outcrops.

Figure 6. **The Segre, Noguera Ribagorçana and Sió rivers flood plains, including low terraces are marked. Blanks are non covered Urgell lutite and sandstone formation outcrops. Discontinuous pyrenean massifs with Mesozoic rocks in the northwestern corner are not drawn.**

Recent and active alluvial fans develop over depressed lutitic plains, almost closed or completely endorreic, like the Urgell Plain (Castell del Remei field trip site) and the plain enclosed by the Barbastro-Balaguer anticline and the Segre and Noguera Ribagorçana river terraces (Algerri field trip site).

Two alluvial fans lie on the Urgell Plain, fed by floods occurring in the rivers d'Ondara and Corb. The erosion in their source area picks up gypsum sediment from the lacustrine Oligocene formations and Eocene Cardona formation outcrops. The alluvial fan at the Algerri site is very much smaller and has its source area in the oucropping of the Barbastro formation at the Barbastro-Balaguer anticlinal core, only few kilometers northwards.

The dryness is the evident climatic factor in the landscape of the western Central Catalan Depression and Ebro Basin aragonese sector (Monegros). It is evidenced by the sharpness of the structural mesas and cuestas, by the dry flat-bottom colluvially filled valleys (like the Ivorra site one), by the petrocalcic cementation of the oldest alluvial levels, and even by the endorreic depressions with present-day evaporitic sedimentation.

2.3. VEGETATION

The territory of the NE of Iberian Peninsula comprises the three major phytogeographical regions of western Europe: Boreo-Alpine, Euro-Siberian and Mediterranean. Table 16 contains the subdivisions of this regions according to Bolòs (1985) and Bolòs & Vigo (1984).

Table 16. Major phytogeographical regions of western Europe presents in NE of Iberian Peninsula and his subdivisions (Bolòs, 1985). In bold are marked the subdivisions present in the gypsiferous area of Catalonia.

The Boreo-Alpine Region (altitudes over 1600 m)
- The nival or permanent snow belt
- The Alpine belt of natural pastures
- The Sub-Alpine belt, of high-mountain coniferous woods

The Euro-Siberian region (the climax area of deciduous woods)
- The European Atlantic province
- **The European sub-Mediterranean province**
  - The climax area of *Hylocomio-Pinetum catalaunicae*
  - The climax area of *Buxo-Quercetum pubescentis*
  - **The climax area of *Violo-Quercetum faginae***

The Mediterranean region (the climax area of sclerophyllous formations)
- The western oro-Mediterranean province
- **The boreo-Mediterranean province** (climax area of evergreen oaks)
  - The climax area of *Quercetum mediterraneo-montanum*
  - The climax area of *Quercetum ilicis*
  - **The climax area of *Quercetum rotundifoliae***
- The austro-Mediterranean province (climax area of maquis)

The Boreo-Alpine region is restricted only to the higher parts of the Pyrenees, generally in the altitudes over 1600 m.

The Euro-Siberian region (moderately high mountain with high rainfall, montane belt) comprises primarily the climax area of deciduous woods of *Quercus robur, Quercus petraea* and *Fagus sylvatica*; though in areas where the climate is relatively dry and continental the conifers may also dominate, especially *Pinus sylvestris* in the high altitudes and *Pinus nigra* subsp. *salzmannii* below. The lower area of Euro-Siberian region -between 1300-1600 and 500 -1000 m- is the European sub-Mediterranean province. This province forms a transition between the Euro-Siberian region, *sensu stricto*, and the Mediterranean province; the climax of the sub-Mediterranean territory is usually a xeromesophilous deciduous or semideciduous wood. Within the sub-Mediterranean province, the least rainy area is the climax area of *Quercus faginea* woods (*Violo-Quercetum fagineae*). The present-day landscapes of this climax area woods of *Violo-Quercetum faginae* include cultivated grounds mixed with pine groves of *Pinus nigra* subsp. *salzmannii*. The oak groves of *Quercus faginea* are fragmented and restricted to soils not convenients for agriculture or sylviculture. Also have some importance the dry calcicolous pastures (*Aphyllanthion*) and box scrubs (*Buxus sempervirens*) in open habitats.
The Mediterranean region contains the areas with dry summer and normally warm temperate climate of southern Europe. Within this region, the boreo-Mediterranean province corresponds essentially to the climax area of evergreen oak woods. Nevertheless, the climatic conditions of continental areas are

more extreme -with arid summers and winter freezing- than in litoral areas, and its climax vegetation is a wood of "carrasca" (*Quercus ilex* subsp. *rotundifolia*), an evergreen oak adapted to continental mediterranean climate. This oak wood climax area is primarily employed for cereal fields or orchards in the best soils. The oak wood is restricted to stony fields, where it is often substituted by *Pinus halepensis*.

2.3.1. GYPSOPHILOUS FLORA AND VEGETATION

Gypsophilous flora include the characteristics plants of gypsum soils, whilst gypseous plants are all those which live in the soils with gypsum.

In the NE of Iberian Peninsula, the major gypsophilous species of vascular plants are:

Campanula fastigiata (Campanulaceae)
Gypsophila struthium subsp. *hispanica (Caryophyllaceae)*
Gypsophila perfoliata subsp. *ilerdensis (Caryophyllaceae)*
Helianthemum squamatum (Cistaceae)
Herniaria fruticosa (Caryophyllaceae)
Lepidium subulatum (Brassicaceae, =Cruciferae)
Ononis tridentata (Fabaceae, =Papilionaceae)
Reseda stricta (Resedaceae)
Senecio auricula (Asteraceae, =Compositae)

Some of them are displayed in Fig. 7. Moreover, some gypseous plants have preference for the gypsum soils, being the most important:

Stipa barbata (Poaceae, =Gramineae)
Agropyrum cristatum (Poaceae, =Gramineae)
Thymus zygis (Lamiaceae, =Labiatae)
Frankenia thymifolia (Frankeniaceae)
Eurotia ceratoides (=Kraschenіnnikovia, Chenopodiaceae)

Most of these species are iberic or ibero-magrebian -NW Africa- endemisms, although some of this plants have chorological affinities with plants of the subdeserts areas of eastern Mediterranean countries (*Campanula fastigiata, Stipa barbata*) or with plants of the estepic areas or eastern European countries (*Agropyrum cristatum, Krascheninnikovia ceratoides*).

There are also some gypsophilous lichens in the area, as:

Acarospora nodulosa
Diploschistes diacapsis
Fulgensia fulgida
Squamarina lentigera

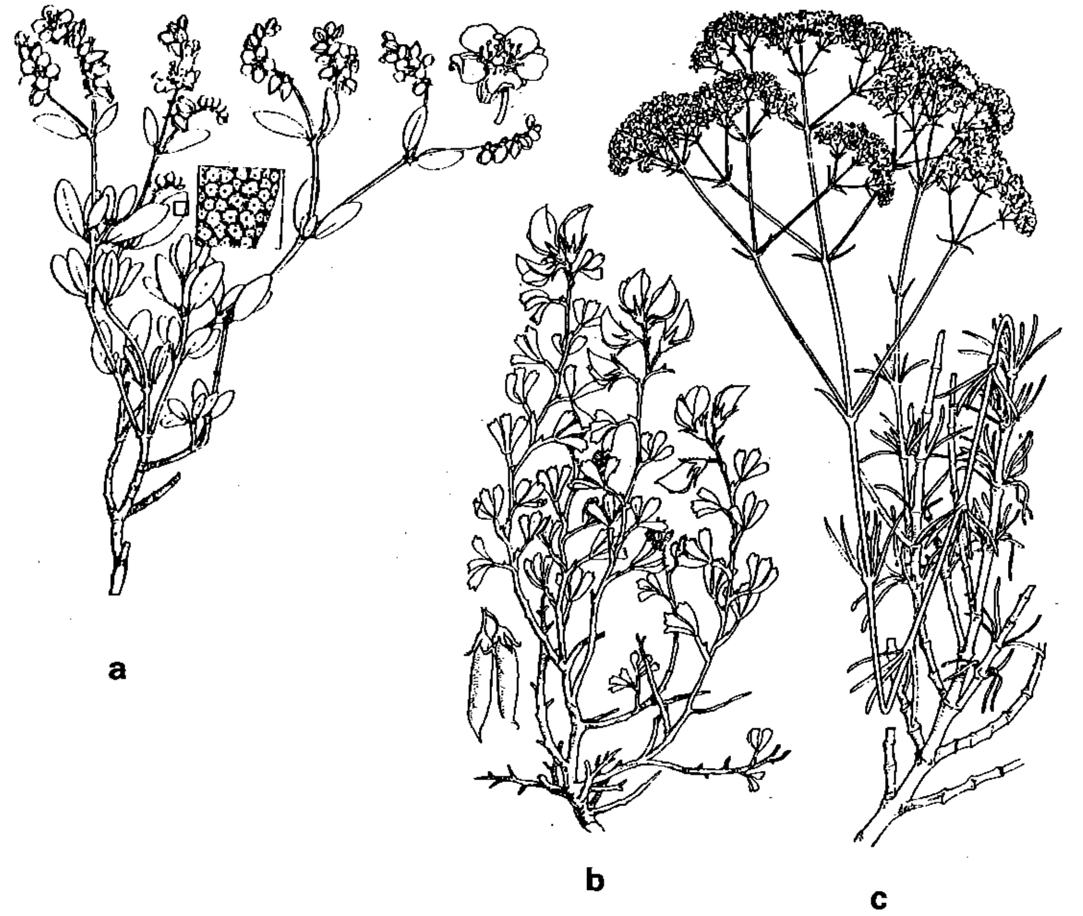


Figure 7. Some gypsophilous species of vascular plants: a) *Helianthemum squamatum*, b) *Ononis tridentata*, c) *Gypsophila struthium* subsp. *hispanica*. (Folch, 1986).

The development of gypsaceous vegetation is related to the development of the soils. When the soil consists of gypsum rocks or they are at shallow depth, the vegetation is poor and have little plants; when the soils are more evoluted the biomass and soil cover by vascular plants are high.

The typical gypsaceous communities of mediterranean and submediterranean areas are included traditionally in the phytosociological alliances *Gypsophilion* and *Agropyro-Lygeion*.

Gypsophilion includes the formations of xerophylous scrubs developed on gypsum soils; whilst *Agropyro-Lygeion* join the communities of the annual mediterranean plants, also gypsaceous.

The scrub formation characterised by *Ononis tridentata* and *Gypsophila struthium* is the most frequent in the area; its height reaches 0,5-1 m and it is relatively compact. It develops on gypsaceous more or less developed soils. *Helianthemum squamatum* is the characteristic species of another gypsaceous community developed on skeletic soils. It is 20(30) cm high, and although it has a low density of vascular plants, the protection of the soil is assured by an important coverage of lichens. Community of *Lepidium subulatum* is similar, but it is developed on gypsaceous natural walls.

2.3.2. VEGETATION OF THE EXCURSION SITES

2.3.2.1. VEGETATION OF THE IVORRA SITE EXCURSION

The location of Ivorra is, in a phytogeographycal view, in the climax area of *Quercus faginea* wood (*Violo-Quercetum fagineae*), but it is near to the northern limit of climax area of *Quercus rotundifolia* wood (*Quercetum rotundifoliae*) (Fig. 8).

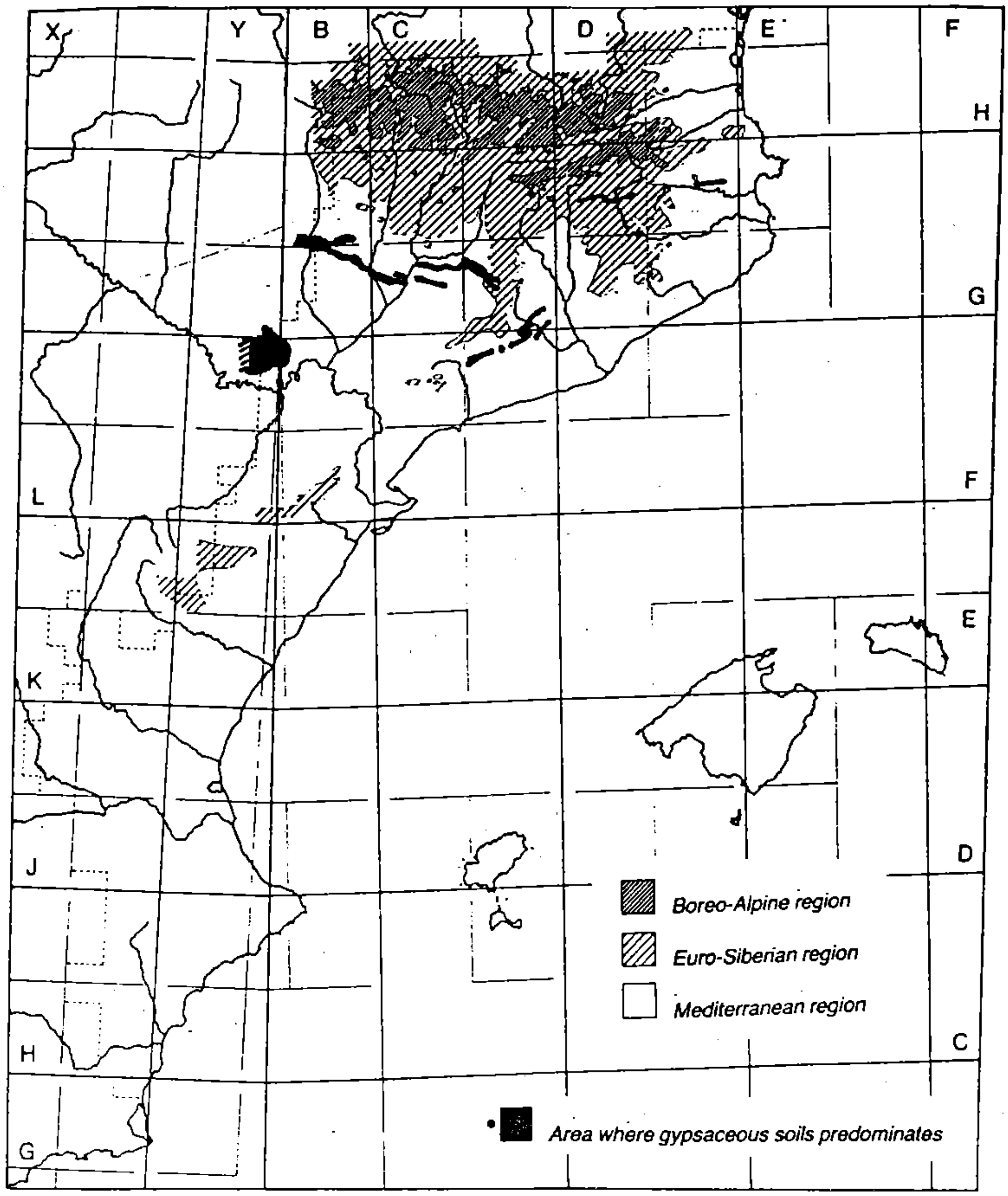


Figure 8. Phytographical regions of NE Iberian Peninsula and areas with gypsum (Bolòs, 1985).

The natural vegetation is rather degraded and its destruction is helped by the ocupation of the land for agricultural uses. Some little groups of oaks are still in the worst lands for agriculture, particularly in shaded places. The growth of *Quercus faginea* is limited by its explotation for fire-wood. The open sites between the oaks are occupied by box (*Buxus sempervirens*) scrubs or by dry calcicolous pastures of *Aphyllanthion*. In the sunny, more arid slopes, there are scrub communities of *Gypsophilion*, with *Ononis tridentata* and *Gypsophila struthium*.

2.3.2.2. VEGETATION OF THE CASTELL DEL REMEI EXCURSION SITE

The location of "Castell del Remei" is, in a phytogeographycal view, in the climax area of *Quercus rotundifolia* wood (*Quercetum rotundifoliae*), but the actual vegetation is representative of the permanent vegetation of this area when the phreatic level is shallow and soil gypsum contents are high. In figure 9 there is a scheme of herbaceous permanent vegetation of this area (Mayoral, 1994).

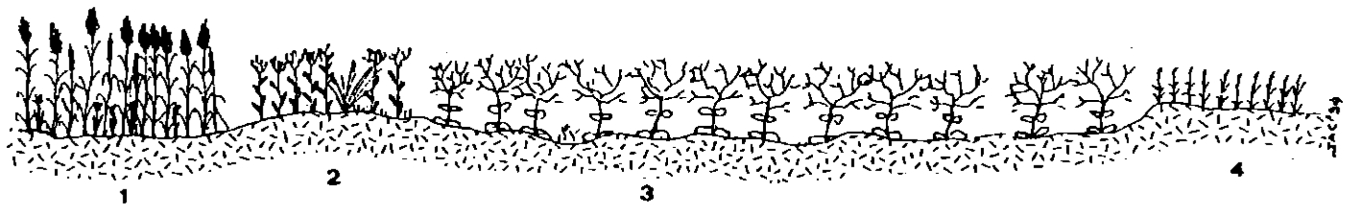


Figure 9. Scheme of herbaceous vegetation on gypsum soils near "Castell del Remei". 1, *Typho-Schoenoplectetum glauci*. 2, *Soncho crassifolii-Juncetum maritimi*. 3, *Gypsophyletum ilerdensis*. 4, Cultivos (*Roemerio hybridae-Hypecoetum penduli*). (Mayoral, 1994).

In this area it is very interesting the presence of *Gypsophila perfoliata* subsp. *ilerdensis*, and in fact Castell del Remei is the only station of this plant in the Ebro valley -other stations are found in la Mancha, near Madrid-. This *Gypsophila* has phylogenetic affinities with *G. perfoliata* subsp. *perfoliata* of the eastern Mediterranean zone. Here we can also find the iberian endemism *Sonchus crassifolius*, which has a very restricted distribution.

2.3.2.3. VEGETATION OF THE ALGERRI-BALAGUER EXCURSION SITE

The location of Algerri-Balaguer is, in a phytogeographyc view, in the climax area of *Quercus rotundifolia* wood (*Quercetum rotundifoliae*), but close to the northern limit of the climax area of *Quercus coccifera* maquis (*Rhamno-Quercetum cocciferae*).

At present, the degradation and destruction of the natural vegetation of this area is very high, taking into account the intense antropic activities developed in the area -land ocupation for agricultural uses, plant harvesting for fire-wood and sheep pastures-.This antropic pressure has absolutely destroyed the evergreen oaks woods. The actual vegetation is the typical one found at the end of regressive series of vegetation: the halo-nitrophilous community of *Salsola vermiculata* and *Artemisia herba-alba* is found everywhere, being the scrubs and the annual plant communities very rare.

2.4. SOILS AND LANDUSE

The so called Central Catalan Depression is the eastern part of the Ebro Basin. It drains to the Segre river and goes from the Catalonia-Aragon administrative boundary in the West to the water divide in the east and south; the north is closed by the Montsec ranges, being these ranges excluded from the present discussion. Strictly speaking in the Central Catalan Depression the elevation goes from near 100m (Granja d'Escarp) to about 1000m.

The larger part of the area is made by geological materials rich in calcium carbonate; the rest are gypsiferous materials. Because of that development, morphology and character-istics of these soils are strongly linked to the calcium carbonate and gypsum contents. As it is described in **2.2. Geology and Geomorphology**, the geological strata from the Tertiary are in a horizontal position, only sloping around the Barbastro-Balaguer anticline and its different branches. Quaternary deposits occupy a large acreage in the center of the area mainly as terraces and alluvial fans. Infilling of valley bottoms and footslope deposits by fine sediments is very important in the rest of the area. Aeolian deposits are very scarce.

At the present moment a large part of the area is cultivated; irrigation is practiced around the city of Lleida (approximate radius of 40 km) and the main rivers, whereas dry farming is predominant in the rest. Only the most sloping or the rocky areas are uncultivated, being occupied by "natural vegetation" which is grazed in many points by herds of sheep. Formerly the extent of cultivated area was even larger than at present, with a maximum at the end of the last century. Soil and water conservation has always been an important issue. In the past terraces ("bancales") and especially stone wall terraces had a very large acreage; in the sixties a change took place from mixed cereal and tree growing with animal power to fully mechanized cereal growing, leading to the abandonement of marginal areas and the removal of thousands of kilometers of terraces. At this moment these terraces are maintained mostly at the south of Lleida (the driest part which still has tree growing) and partly in the most sloping lands. As a result of these changes in landuse, erosion has intensified.

Irrigation was practiced traditionally along the terraces of the main rivers (Segre, Noguera Ribagorçana, Noguera Pallaressa, Farfanya, Sió, Corb, Set) probably back to the middle ages; in 1864 a canal from the Segre river was built (Canal d'Urgell) with later developments from the Noguera rivers making around 130.000 km (Gabinet Tècnic, 1996) of irrigated land. Those developments were linked, in some areas, to drainage and salinity problems. To cope with these large amounts of drainage works have been done since then.

The former paragraphs are ment to explain why man is a key factor to understand soils in the Central Catalan Depression. The principal soil forming processes present in the area (accumulation of organic matter, erosion - sedimentation, translocation of carbonates and gypsum, development of soil structure, redox conditions, salinization-sodification) are modified by man with strong changes. Under the present combination of soil forming factors calcium carbonate is not fully removed, even from the topsoil; only in very few patches, which are geomorphic stable areas with remnants of forest, decarbonation is clearly observed. This leads to the fact that soils are calcareous throughout the area.

The main soil types present are Typic and Lithic Xerothents, Typic Xerofluvents, Calcixerollic Xerochrepts, Petrocalcic Xerochrepts, Gypsic Xerochrepts, Fluventic Xerochrepts, Xeric and Lithic Torriorthents, Xeric Petrocalcids, Oxyaquic Xerofluvents with minor extents of Gypsids, Calcids and other soils. Figure 10 shows some general soil landscape relationships in the way from Ivorra to Cervera. Dominant diagnostic horizons are ochric, calcic, petrocalcic, gypsic and cambic.

Farming is done by private farmers, which usually own several fields situated around the villages. In the dryland area the main crops are barley, almonds, olives and some vineyards. Their average yields are given in Table 17. In the irrigated land cropping is more diverse. The typical rotation is alfafa-wheat-maize, but it also exists maize as a monoculture. Fruit trees (apples, pears, peaches), horticulture (onions), vineyards and barley are important as well. Table 18 summarizes their average yields.

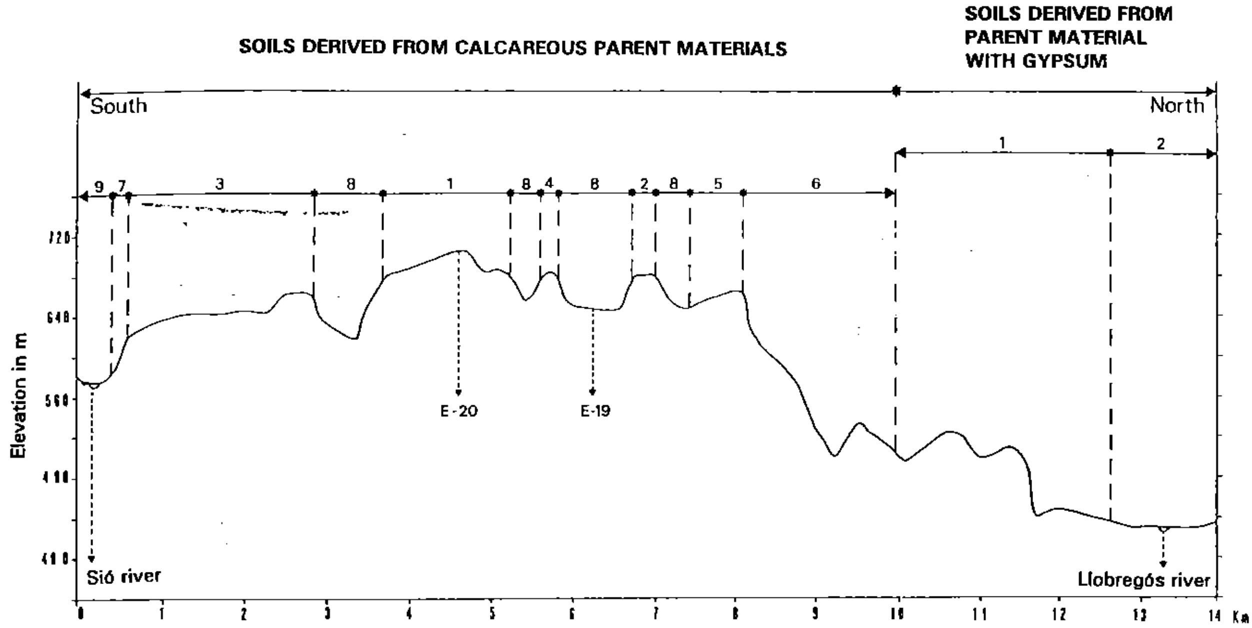
The Ivorra area belongs to a more subhumid dryland area, devoted almost entirely to barley. Almonds and olives are marginal. The soils of alluvial deposits (Urgell site) are irrigated since 1864. The crops in the gypsum area do not differ from the rest of the irrigated area, being only excluded from the more gypsiferous soils the fruit trees and the vineyards. The Algerri site corresponds to a more arid area under dryland conditions. Barley is the main crop.

Table 17. Average yields for different crops in the Central Catalan Depression: Drylands (Adapted from Gabinet Tècnic, 1996)

Crop	Average yields (Tm/ha)
Almond	1.1
Barley	3.3
Grapes	3.9
Olives	0.45
Wheat	2.8

Table 18. Average yields for different crops in the Central Catalan Depression: Irrigated land (Adapted from Gabinet Tècnic, 1996)

Crop	Average yields (Tm/ha)
Alfalfa	65.0
Apple	22.5
Barley	5.0
Maize	8.2
Onion	35.0
Peach	14.5
Pear	13.1
Wheat	5.4



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 chesa area
2. Soils of the alluvial valley.
   Calcic Cambisols (Cambic Gypsiorthids) with inclusions of Calcaric Fluvisols (Typic Xerofluvents).

Figure 10. Soil pattern in La Segarra from Sió river to Llobregós river through Ivorra site, according to FAO (1974) and SSS (1975) (adapted fromBoixadera,1985)

3. SOILS WITH GYPSUM ACCUMULATIONS IN THE CENTRAL CATALAN DEPRESSION

3.1. SOILS ON TERTIARY GYPSUM OUTCROPS (IVORRA SITE)

This chapter gives a general introduction to the field trip in the Ivorra area, and data about the macromorphology, micromorphology, chemical composition and behaviour of the soils. Its purpose is to allow on-site discussion during the field trip.

More detailed description (in Spanish) of the soils and the thin sections with microphotographs can be found in the book by Herrero (1991), that is the main source of information for this chapter. The article in English by Herrero et al. (1992) presents the most relevant soil features of this trip. The location of the pedons to be visited is indicated in Fig. 11.

3.1.1.SOIL-LANDSCAPE RELATIONSHIPS

As we approach to the gyprock outcrop in the core of the Barbastro-Balaguer anticline, we take a look from a distance of several km (Stop 1) to realize the distinct contrast of the gypsum area. This is due not only to the white color of the gyprock, but also to its differential erosion against other rocks. The relief is hilly, and the general altitude is lower than the surrounding areas that have more resistant rocks like limestone and sandstone. The folk name of *chesa* (from aragonese cheso = gypsum) is proposed for the lands on gyprocks.

When we are located within the chesa, in the Ivorra site, we become aware of the outstanding landscape feature on the gyprocks outcropping in the Ebro basin, a more or less intricate pattern of valleys that separate rounded hills. The proposed name for these valleys is *vales* (singular: *val,* from aragonese val = valley)), that is widely used by geomorpho logists and geographers in the Ebro vallley. The dissection by *vales* produces (Herrero et al., 1992) six general landform units: hilltops, sun-facing hillslopes on gyprock, shaded hillslopes on gyprock, hillslopes on gyprock with calcilutites, saddles and stable footslopes, and valley bottoms. These landforms can be related to soils and vegetation (Fig.12).

In general, only the *vales* bottoms are cultivated. Rainfed agriculture relies on winter cereals, with barley the most common crop. Small plantations of almond trees have become uneconomic. Gypsum quarries and waste disposal are quite frequent in chesas, which are often seen as marginal lands.

The infiltration characteristics of these soils show high spatial variability (Table 19). This variability can be related with surface conditions like ploughing or plant cover in sites with thick soils. In the very common thin soils, infiltration is related to rock conditions like composition and strata inclination, that are also very variable due to folding of strata, and govern the local karstification of the gyprock. In spite of the high infiltration variability, Table 12 shows that the bottoms of valleys (vales) have lower infiltration capacity, agreeing with the runoff concentration that produces gullies and ravines in the bottoms of vales.

Table 12. Range of the basic infiltration rate (i_{te}) measured by the Muntz method in soils on several landforms of Ivorra.

Landform	Pedon	Number of measuring sites	i_{te} mm/mn
Hilltop	IB 153	5	2.1-14.1
Saddle	IB 135	1	10.4
Sun-facing hillslope	IB 136	1	6.6
Valley bottom (ploughed)	IB 137	2	0.8-2.7
	IB 142	2	2.8-4.0

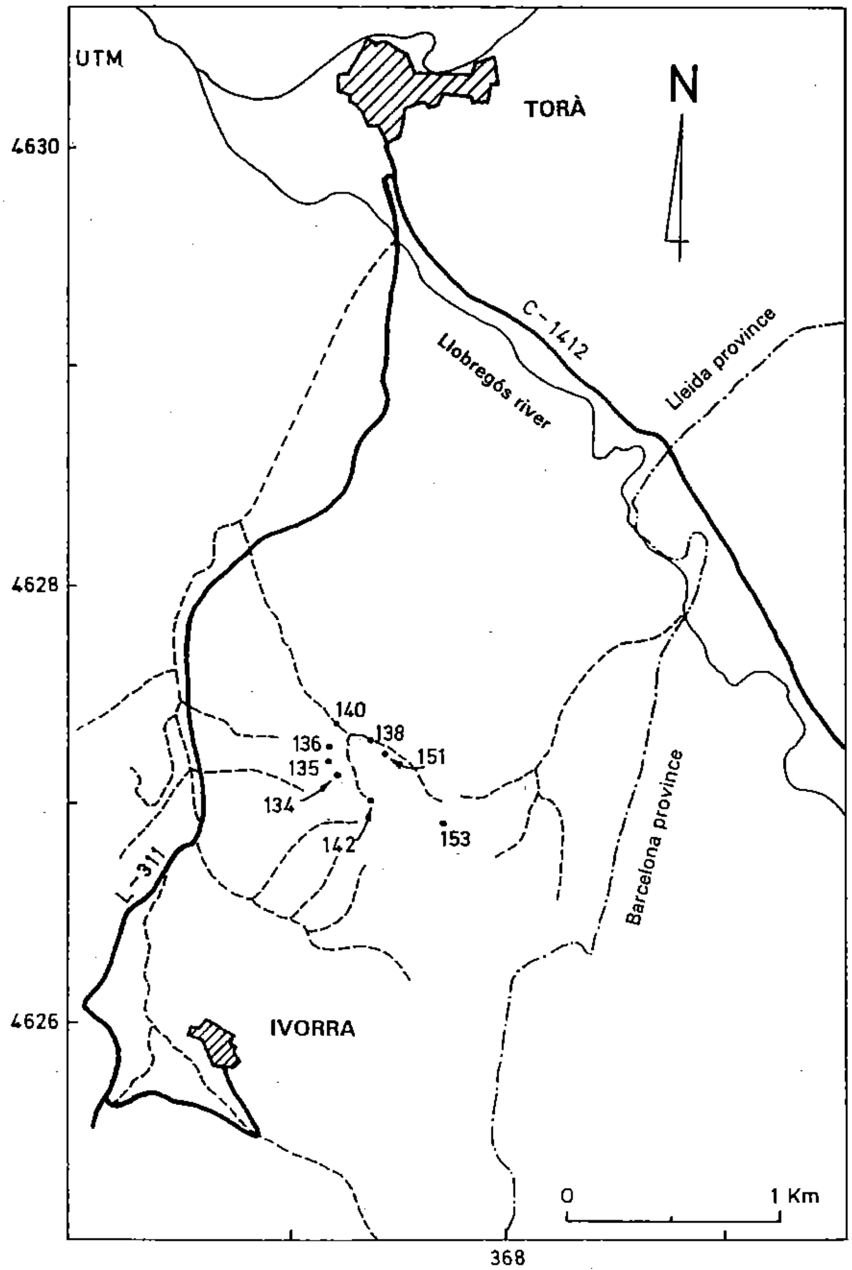


Figure 11 Location of the soils described in the excursion guide (Ivorra site).

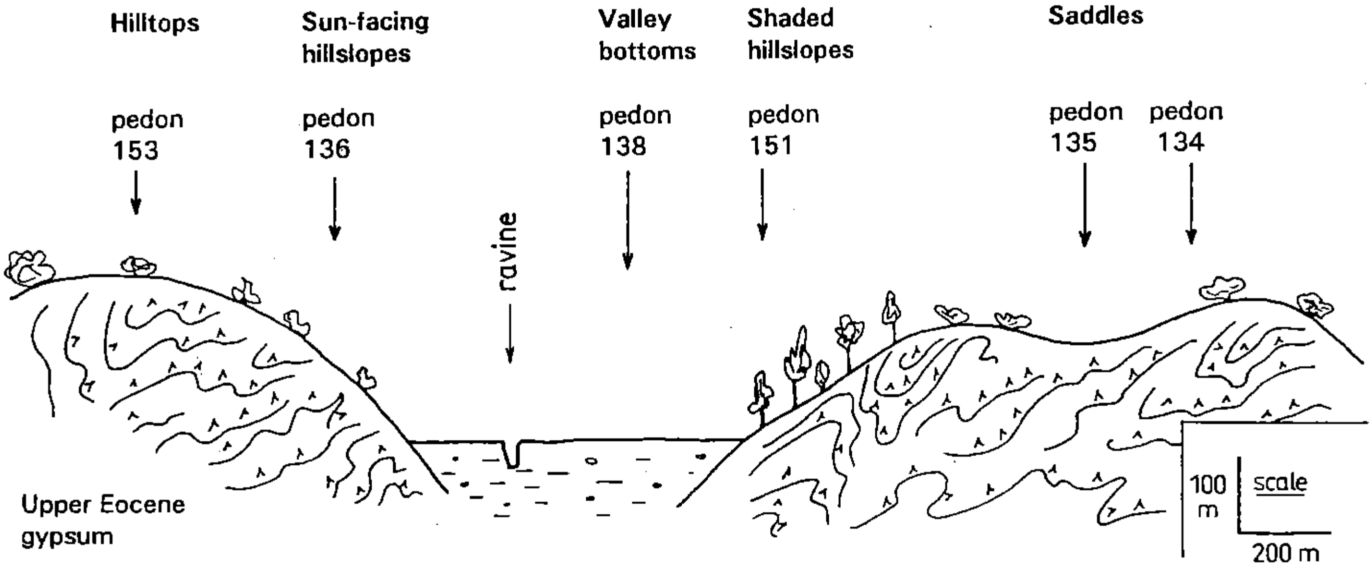


Figure12. Outline of the pedons to be visited in Ivorra, and their landscape distribution.

3.1.2. DESCRIPTION OF SELECTED PROFILES

3.1.2.1. SOILS ON HILLTOPS

Some relatively flat hilltops can support a natural vegetation, including some trees (*Quercus faginea* Lam.) and shrubs (*Ononis tridentata* L., *Quercus coccifera* L., *Rosmarinus officinalis* L.), and a dense coverage of lichen and moss. These hilltops can have some calcilutite interbedded in the gyprock, favouring water retention and the development of a soil. All these conditions result in soils several decimeters deep, with metric pockets up to 150 cm deep. These soils in general occurs in spots of less than 1000 m^2.

In the field, these soils are characterized by two kinds of materials, the flour-like gypsum (microcrystalline gypsum under the microscope), and a loose sandy material (quesparite grains under the microscope) often accumulated in the base of some shrubs together with vegetal residues. In general, both materials can be separated only under the microscope. The quesparite material is mainly composed of individual grains of quesparite, but contains whole queras and all stages of decaying queras. Submillimetric nodules of microcrystalline gypsum occur scattered in the groundmass of quesparite grains. Microcrystalline gypsum can produce a groundmass. Small amounts of millimetric gypsum lenses are always present, according to their ubiquity in the area.

Because of their landscape position and their loose constitution, these soils are prone to erosion if vegetation is eliminated. The infiltration characteristics (Table 19) of these soils are very variable depending not only on the surface cover but also on the depth of the rock and the local degree of karstification of the rock.

Information about soils on hilltops.

The extension or the local rock characteristics of some hilltops plus specific management practices, allow a continuous vegetal cover. The surface inspection of these hilltops and their associated gentle slopes reveals frequent decimetric deep accumulations of loose material under shrubs. This material is covered by and mixed with leaves and other plant residues, and may be the substrate for lichens and moss. These accumulations of loose material can coalesce producing a continuous horizon (pit IB153). Tables 20 and 21show the field and chemical characteristics of this profile.

Most of the mineral soil material is a mixture of single quesparite and lenticular gypsum crystals plus queras in several decay stages and some fine material (micrite and microcrystalline lenticular gypsum) more or less aggregated. A name for this quesparitic horizon will be needed if these kind of horizon is found in other areas.

Table 20 Summary field description of pedon IB153

Depth cm	Color	Structure	Organic matter	Roots	Coarse fragments	Boundary
0-100 ↓	7.5 Y 8/2 dry	Structureless, single grain.	Organ residues.	Few, fine and very fine, alive.	None.	Abrupt, wavy.

Table 21 Analytical data pedon IB153.

Sample reference	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25°C	Particle size distribution
153-1	0-15	7.8	3.8	40.0	26.4	1.57	flocculate
153-3	0-15	7.9	1.6	36.6	45.7	1.96	flocculate
153,0-1	0-1	-	-	49.4	-	1.72	-
153,0-17	0-17	-	-	16.5	-	2.12	-
153,17-33	17-33	-	-	33.5	-	1.96	-
153,37-63	37-63	-	-	36.2	-	1.67	-

Saturated paste										
Sample reference	Hs (%)	CEe dS/m 25°C	cmol(+,-) / l							SAR
			Ca^{2+}	Mg^{2+}	Na^{+}	CO_3^{2+}	HCO_3^{+}	SO_4^{2+}	Cl^{-}	
153/1	8.4	2.64	37.3	2.5	lp.	ip.	5	29.5	1.8	0
153/3	6.8	2.65	36.0	4.6	lp.	lp.	4	30.5	1.1	0

Micromorphology pedon IB153.

Thin sections IB153-1,3 0-10cm
Thin sections IB153-1 and IB153-3 are very similar, and both representative of the surface of this soil.

MICROSTRUCTURE
Apedal. Simple packing voids, and vughs. Complex microstructure: single grain and vughy.
This thin section only has pedofeatures and organic components.

PEDOFEATURES
1.- **Lenticular gypsum**. The common size of the lentils ranges from 60 to 300µm. Often the lentils contain euhedral or subhedral unidentified inclusions < 4µm. Lenticular gypsum is 10-15% of the section. Lentils are random distributed, with some pockets of lentils with a whirl disposition. The upper 2 cm of the thin section do not have gypsum lentils.
2.- **Radial and palisade gypsum**. The basic distribution pattern is fan-like grading to palisade. The common size of crystals is 300 X 30µm, and their inclusions are less frequent than in the random distributed lentils. This kind of gypsum is < 1% of the thin section surface. The radial disposition, when referred to a central void, produces a transitional disposition to palisade. This kind of gypsum is often associated to gyprock fragments or to microcrystalline lenticular gypsum.
3.- **Microcrystalline lenticular gypsum**. Typic nodules, about 300µm Ø; some of them are elongated or irregular, up to 1mm X 270µm. Often they enclose roots, or they are either in contact to roots or associated to a root's void. These nodules are always opaque under crossed polarizers and yellowish under plane light. The most dense nodules show, under plane light, features seeming undulant longitudinal sections and transversal circular sections of channels (10 to 15µm Ø. Moreover, in some of these nodules occur fine (3µmØ) filaments, looking as biological, perhaps hyphae. Channels are not coincident with filaments. The microcrystalline lenticular gypsum is about 3% of the section surface, and is random distributed across the section, excepted the upper 2cm, where is lacking.
4.- **Gypsum relics**. Gypsum crystals with different shapes, many of them show the starting of lenticular shapes in the borders, probably because dissolution/precipitation. Gypsum relics (<1%) are random distributed across the section, but they lack in the upper 2 cm.
5. **Micrite.** Bodies having sedimentary fabric are very rare. Clastic shapes can be found, but rounded shapes with similar sizes are the most common. Some of these bodies have an area of quedecal, that often are separated by void, but both parts always are accommodated. All stages of desaggregation can be found, until single microcrystals. Some times, lentils appear to play a role in the desaggregation. All kinds of fragments and the microcrystals are random distributed, and mixed with quesparite crystals and with the other soil components.
6.- **Quesparite.** Typical size is about 70µm. They are 30% of the section surface. Random distributed. Most quesparite are single crystals packed with the other soil components; a small proportion of the quesparite occurs as rounded or elongated mosaics, in all stages of breaking up .
7.- **Quedecal**. This material makes rounded aggregates with maximum size of 1.2mm randomly distributed in the section. In some cases, the aggregate has a micritic area and a quedecal area. All stages of decaying can be found, but gypsum lentils within this material is more frequent than within micritic aggregates.

ORGANIC COMPONENTS
The upper centimeter of the section is the alive moss together with residues of unidentified organs. Frequent single quesparite crystals an some micritic aggregates (240 X 480 µm) appear among these materials; lenticular gypsum crystals are very rare. Organic components in the bottom of the section are estimated in 7%. Ranked in decreasing abundance order, these components are the following:
1.- **Root residues**, in all the stages of decay.
2.- **Excrements.** Ellipsoidal sections, around 45µmØ, with smooth surface. They are composed by organic fine and dense material, dark-red colored or opaque. Most excrements occur inside the most altered root residues. The described excrements are attributable to Oribatid mites.
3.- **Amorphous material**. Opaque material that occurs as isolated spots (25µm) or grouped spots. This material is randomly distributed across the section, and also occurs in the quedecal material.
4.- **Filaments**. The coarser (12µmØ) are hyphae and have smooth walls. The finer (6µmØ) show ornaments. Both can be found isolated or in connection to some organic residue. These filaments seems to be different from the kind of filaments described within the nodules of microcrystalline lenticular gypsum.

Thin section IB153: 17-38 cm.
Section representative of the lower horizon, that is quite homogeneous.

MICROSTRUCTURE
Apedal. Simple packing voids. Some ill-defined vughs. Few channels that can be distinguished because loose excremental infillings. Single crystal microstructure.
Randomly distributed pedofeatures are the most important constituents of this thin section. Only 1% are millimetric angular fragments of grey calcilutite. Some of these fragments have a quedecal area looking as the quedecal fragments that are mixed with the other pedofeatures.

PEDOFEATURES
1.- **Lenticular gypsum**. Modal size is 120μm, but minor sizes are common. Coarse lentils, from 800μm up to several mm, also appear in the thin section, and are concentrated along a strike crossing the section. These lentils are similar to those described in the following paragraph.
2.- **Radial and palisade gypsum**. The coarse lentils are often imperfect, or polilenticular, or very sharp, and they have radial dispositions grading to palisade, in association to grey calcilutitic material. Some lentils reach 8 mm, and contain grey calcilutitic material.
3.- **Microcrystalline lenticular gypsum**. 5% of the thin section. Appears as rounded nodules < 800μm, and can be seen naked-eye in the thin section. This kind of gypsum also appears as smaller masses that can occur grouped as irregular composed nodules with desaggregated parts. No channels or hyphae were found.
4.- **Micrite**. Even if the aggregated micrite material (1%) is a lutite residue, it is considered as a pedofeature because its breaking up and because its dispersion among the other pedofeatures. The most common are rounded fragments of 100μmØ, but it grades to independent crystallites. These materials also appear included within gypsum lentils.
5.- **Quesparite**. Single crystals randomly packed with the other components are the most abundant component of the section. Some residues of quemosaics are found, but mosaics having associated quedecal are rare.
6.- **Quedecal**. This material occurs as millimetric aggregates. Most of these aggregates do not have a quedecal part, nor quevoids or association with quemosaics. The most gaudy trait against the quedecal in other sections is the scarcity of birefringent domains and the faint color. In some cases they are, under natural light, more transparent than the microcrystalline lenticular gypsum that is yellow with this light.
7.- **Coatings**. Very few. Some chambers and channels are drawn by a concentration of fine material.

ORGANIC COMPONENTS
Few roots residues with phlobaphene and Oribatid excrements. Some organic residues are broken up and mixed with pedofeatures or associated to some channels.

3.1.2.2. SOILS ON SUN-FACING HILLSLOPES ON GYPROCK

Steepness is frequent on the sun-facing slopes on gyprock. They are commonly bare or have sparse shrubs of *Quercus coccifera* L. that grow in rock pockets or cracks. The shrubs growing on bare gyprock are often associated with decimetric cavities some cm under the surface. These cavities are easily detected by the typical `void` sound when the surface is struck by a hammer, and provide a habitat for some small organisms. Another common feature in the bare gyprock is microkarst, that carves very typical centimetric dissolution rills.

Flour-like gypsum is more frequent on the shaded slopes, but can also be found on sun-facing footslopes. Sun exposure affects this material, which loses its flour-like feel and becomes quite consistent after it dries.

The transport rate is higher than weathering, and only in rock pockets can soils develop. These soils are incipient, with an A-R profile, and thin sections show a groundmass of gyprock fragments and microcrystalline masses (< 1mm) often associated with lichens.

Runoff during storms is important on all hillslopes, but more specifically if the slopes are bare and steep, as are most of those sun facing. The importance of runoff is made clear by the careful anti-erosion trenches and associated linear mounding along the border of the footslopes with the *vales* bottoms.

<u>Information about soils in sun-facing hillslopes on gyprock.</u>

Bare gyprock is very common in sun-facing slopes. The fallen leaves of *Quercus coccifera* L. are carried downslope together with other residues, and a continuous soil coverage cannot develop. Only lichens can live on the bare gyprock. Grazing and fire also play a role, but the difference between sun-facing and shaded slopes is determinant in Ivorra area.

Tables 22 and 23 show the field and chemical characteristics of a representative soil in this position. Soil in this kind of slope is ruptic because only develops within rock anfractuosities. The sampling of undisturbed blocks is difficult also because these soils are thin and loose.

Table 22 Summary field description of pedon IB136

Horizon Depth cm	Color	Structure Friability	Organic matter	Roots	Coarse fragments	Boundary
A1 0-2/40	10 YR 5/3 moist.	0-2 cm fine granular strongly developed; 2 cm subangular blocky, weakly developed. - Friable.	Few well incoporated.	Fine to coarse, few, horizontal orientation.	Few, gravelly, tabular-subangular gypsum with dissolution forms.	Abrupt broken
R 2/40 -↓	Gyprock					

Table 23 Analytical data pedon IB136.

Sample reference and horizon	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25°C
136, A1	0-2/40	7.34	1.9	3.3	82.4	2.00

Saturated paste										
Sample reference	Hs (%)	CEe dS/m 25°C	mmol(+,-) / l							SAR
			Ca^{2+}	Mg^{2+}	Na^{+}	CO_3^{2+}	HCO_3^{+}	SO_4^{2+}	Cl^{-}	
136	38.4	2.91	39.0	2.0	1.0	Ip.	3	36.0	ip	0.2

Sample reference	Exchange cations (cmol+/ kg)				CEC (cmol+/kg)
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
136	5.90	1.90	0.15	0.20	8.15

Micromorphology pedon IB136.

Thin section IB136 0-8'

MICROSTRUCTURE

The pedality of the upper 0.5 cm of the thin section is strongly developed, with rounded peds ranging from 0.5 to 1.5 mmØ, unaccomodated. Complex packing voids in 60% of the section surface. Granular microstructure, grading to spongy in some areas. The pedality in the inferior area of the thin section is weak, with subangular blocks. Voids show a horizontal trend.

The materials of the thin section are described as pedofeatures and organic components.

PEDOFEATURES

1.- **Lenticular gypsum**. Rare.

2.- **Microcrystalline gypsum**. Yellow masses of microcrystalline gypsum occur in the upper part of the pedon. Gypsum lentils (16µm) are sharp. This material can be found with two presentations (i) as the lichen's pruine both on the algal layer and within the felt of hyphae (3µmØ) in the base of the lichen, and (b) as masses associated to the granoblastic or porphyroblastic rock fragments. The microcrystalline lenticular gypsum is in the soils surface, and pervades the gyprock. The mass of microcrystalline gypsum contains hyphae (3 µmØ) and some vughs with a green body, probably an algae. A clear connection between the hyphae and the algal bodies was not observed. Some isolated crystals of anhydrite can be seen inside the porphyroblasts.

3.- **Gyprock relics**. Most of the lower part of the thin section contains fragments of porphyroblastic gyprock. All stages are found, from fragments of saccharoidal gyprock with several porphyroblasts, to single porphyroblasts and a majority of single irregular gypsum crystals. These crystals can be considered as the end step of the saccharoidal gyprock degradation.

4.- **Micrite**. Isolated micritic fragments < 1mm, some of them contain organic residues and anhedral gypsum crystals.

5. **Quesparite.** Quesparite crystals isolated or grouped by two or three. Most of these crystals appear in the upper part of the thin section, some of them included in the aggregates. Areas showing concentration of quesparite

crystals occur in the bottom of the thin section, but they do not appear as mosaics.
6. **Quedecal**. Some small aggregates appear in the upper part of the section. Their decalcified appearance and b-fabric suggest that they are fragments of queras, but their attribution is not sure because they occur as isolated small fragments. Big fragments attributable to queras appear only in the bottom of the section. These fragments usually neighbor the accumulations of quesparite crystals. Both materials appear among big gypsum crystals with semilenticular contour.
ORGANIC COMPONENTS
Weakly altered residues of Quercus coccifera leaves are frequent in the surface. These residues contain phlobaphene and euhedral crystals, probably whewellite. Some hyphae are associated to these residues.
Under the leaves, a millimetric layer made by residues of unidentified tissues appears. This layer contains the microcrystalline lenticular gypsum nodules already described, with algae and hyphae. In this level also appear lichens with microcrystalline lenticular gypsum in the pruine.

Ovelying the gypsum horizon, it appears a layer of 2 to 10 mm depth made by an aggregated material, already described in the Microstructure paragraph. This material has fecal appearance.
The bottom of the section is made by gypsum, and by all kind of residues showing a high degree of alteration and comminution.

3.1.2.3. SOILS ON SHADED HILLSLOPES ON GYPROCK

Hillslopes facing north, or at least not directly facing south, are in general gentle compared with sun-facing hillslopes. They can have *Quercus faginea* Lam. and a dense shrub coverage. The transport along the slope is limited, and the typical profile has an O-A-Y-R sequence of horizons.

In deforested areas, the soil material may be transported away from its original site under the influence of gravity when water accumulates in the soil. The material eventually starts to flow downslope as a mudflow. This mass movement of gypsum material is more active in winter, when the flow develops and makes mud tongues (Fig. 13). The average size of a typical tongue is 24 m long, 18 m wide and 70 cm deep. The maximum displacement of those measured was 45 m. The flows of different years that have been identified are all less than 20 years old. This material allows further establishment of vegetation, but a laminar structure often remains. Decimetric fragments of flour-like material were found within the surface horizon of soils of the valley bottoms; these fragments could be either the remaining of past mud flows or could be incorporated by farmers.

The Y horizon can be more than 1 m thick in some cases and, when wet, has a flour-like feel. Data from chemical analyses indicate that the gypsum content can be up to 95%. Under a polarizing microscope, the groundmass is microcrystalline gypsic with sparse silt-size carbonate. Voids are horizontally elongated vughs, occasionally coated with silt-size carbonate. Some millimetric nodules of purer microcrystalline gypsum alter the void pattern in the well-developed flour-like Y horizons.

Information about soils in shaded hillslopes.

The microcrystalline lenticular gypsum horizon is an outstanding soil feature that, after its description in shaded hillslopes of Ivorra, was identified in different pedons on several landscape positions in this area. The same horizon has been later recognized in other chesas in the Ebro valley. This horizon can have more than 95% gypsum and the field diagnosis is easy because of its flour-like feel and by its white or white-pinkish color.

Tables 24 and 25 show the morphological and analytical data of the representative pedon in these positions (IB 151).

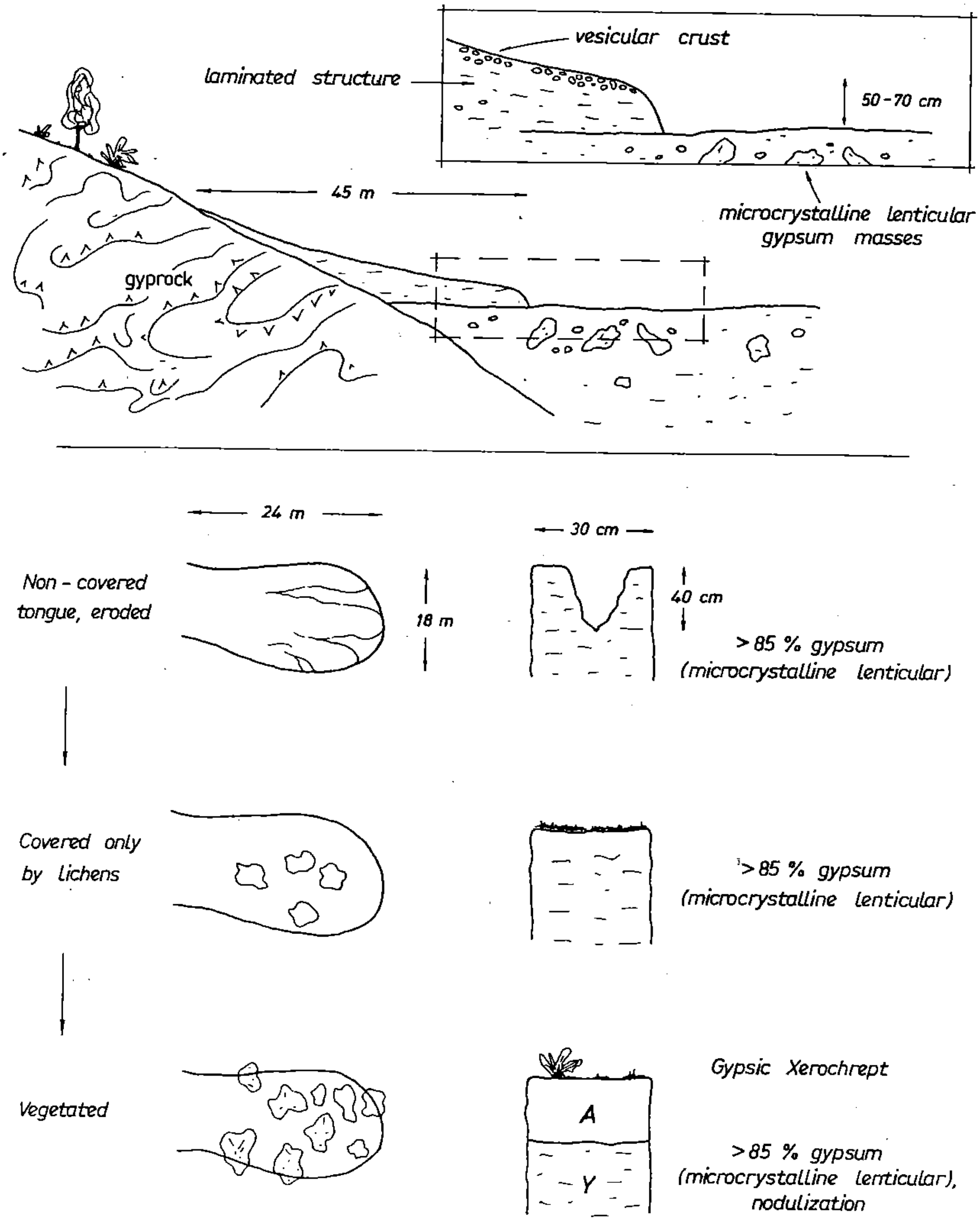


Figure 13. Observed downslope movement of flour-like gypsum in Ivorra, and evolution of the tongue shaped deposits.

Table 24. Summary field description of pedon IB151

Horizon Depth cm	Color	Structure Friability	Organic matter	Roots	Coarse fragments	Boundary
O1 0-2	7.5 YR 3/3 moist.	Organic layer.		Abundant, fine to medium, horizontal, alive.	None.	Abrupt, smooth.
A1 2-27	10 YR 3/3 moist. 10 YR 6/3 dry.	Moderately developed medium granular. Friable.	Abundant, well incorporated	Abundant, very fine to coarse, alive.	None.	Abrupt, smooth.
Y 27-90	10 YR 3/3	Weakly developed, fine, subangular blocky. Friable.	None.	Few, very fine to coarse, horizontal.	None.	

Table 25. Analytical data of pedon IB151.

Sample reference and horizon	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25°C
151/1, O1	0-2	7.3	50.3	26.0	-	2.01
151/2, A1	2-27	7.6	6.4	42.5	0.8	0.24
151/3, Y	30-45	7.8	1.0	-	95.9	2.25

Reference	Particle size distribution				Saturated paste					
	Sand		Silt 0.05-0.002 mm	Clay <0.002 mm	Hs (%)	CEe dS/m 25°C	cmol(+,-) / l			SAR
	2-0.5 mm	0.5-0.05 mm					Ca^{2+}	Mg^{2+}	Na^{+}	
151/1	-	-	-	-	241.6	2.91	37.0	4.0	1.0	0.2
151/2	1.41	11.51	47.77	39.31	57.2	1.23	15.0	2.0	1.0	0.3
151/3	-	-	-	-	50.0	2.48	35.0	3.0	1.0	0.2

Micromorphology pedon IB151

Thin section IB151: 0-9

O1 Horizon

Soil surface is covered by organ residues, mainly leaves, with hyphae that become more abundant in depth.

Rounded or oval fecal pellets of around 1.2 X 0.9 mm are mixed with comminuted organ residues, making an underlying layer. Several stages of pellets decay appear. Hyphae are abundant.
Voids are 80% of the section surface. Microstructure is granular complex of organic residues and fecal pellets.
A Horizon
Strongly developed pedality. Subangular blocks < 8mm in the 40% of the section, partially accommodated. Inter-aggregate voids are zig-zag planes, channels and chambers; intra-aggregate voids are irregular vughs. The other 60% of the section are rounded blocks ranging from 120µm to 600µm in diameter, with complex packing voids. Microstructure is complex. An area has subangular blocks, and the other has complex packing voids with spongy zones.

GROUNDMASS
Coarse material

-quartz: 60µm, unsorted, angular. The coarser grains are elongated and <200µm.
-**calcilutite**: modal size 200 to 250µm, some crystal can reach 0.9mm. Spheroidal or slightly oblate, rounded, with distinct smooth edges. Micritic b-fabric.
Both quartz and calcilutite (<1%) are integrated in the groundmass, and only exceptionally occur isolated within voids.
-**sparite**: 90µm, well sorted. Abundance 7% Most are loose crystals within the blocks, and seems to be quesparite. Only some bigger crystals (up to 320µm) have cleavage and other internal characteristics of calcite.

Fine material.
Crystallitic b-fabric. The related distribution coarse/fine distribution is porphyric.

ORGANIC COMPONENTS
Plant residues appear in all stages of decay. Some roots residues contain oblate excrements, 30 µmØ. The well decomposed residues and the amorphous organic material are incorporated into the groundmass.
Hyphae (8µmØ) are frequent, associated to root residues. Ramified filaments, Ø < 2µm. Sporangia are frequent.

PEDOFEATURES
The pedofeatures are crystallitic. Nodules with recrystallizations: The nodules are micritic, with microsparitic (7µm crystals) or sparitic (crystals up to 70µm) domains, that are considered recrystallizations. The nodules are elongated and lobulated, with sizes up to 0.7 x 1.1 mm. Most sparitic domains are in the nodules edges or associated to the frequent irregular voids of the nodules. The nodules' edges are not distinct, but they look different from the impregnative nodules that have been described in other thin sections in Ivorra. The nodules use to have inclusions of groundmass, sometimes associated to voids. Frequent brown spores (5µmØ) in clusters included in the micritic mass. Some hyphae appear in association to the nodules edges. The abundance of these nodules is <1%, and they are more abundant in the more vughy areas of the thin section.

Thin section 151: 9-17

MICROSTRUCTURE
Strong aggregation. Accommodated subangular millimetric blocks in 40% of the thin section. Another 40% are rounded blocks with assorted sizes (70µmø is modal), and most are channel infillings with different degrees of aggregates' coalescence. Voids are 20% of the thin section. Channels and chambers are the most common, followed by craze planes. In the infilling areas, most are complex packing voids, and some channels and chambers. Intraaggregate voids are vughs.
Channels and chambers microstructure, and very weak of subangular blocks. In the infillings, microstructure is crumby or granular, with areas in transition to spongy or vughy that are similar to the aggregates not belonging to the infillings.

Coarse material

-**quartz** in the aggregates, 30-40µm, well sorted, angular-spheroidal or subrounded-spheroidal. Some are elongated, up to 60µm long, and some other are rare, angular, up to 240µm long. The total of quartz is 2% of the thin section surface.

-micritic fragments, 2% of the thin section. Fragments <1.8 mmø, rounded-tabular or rounded-spheroidal. Crystallitic b-fabric. Porphyric c/f related distribution.

ORGANIC COMPONENTS
All alteration stages of plant residues, some of them containing brown oval excrements (30µm). The amorphous organic material and the more decomposed residues are incorporated into the groundmass. Hyphae are rare. Sporangia occur as in the overlying horizon.

PEDOFEATURES
1.- **Anhedral sparite.** Crystals with regular distribution in the groundmass. Because the size (90µm) and general characteristics, most of them seem to be quesparite in different corrosion stages. Some individuals are in transition to bigger euhedral or subhedral crystals, loosing the quesparite appearance, and some crystals have a 70° lozenge section and a size up to 180x120µm. All quesparite is a 10% of the thin section. Only one case was observed of grouped quesparite crystals having the appearance of a quemosaic. They are enclosed by micrite and show spores' clusters in the contact micrite/sparite.
2.- **Nodules with recrystallizations.** Shape and composition are similar to the above horizon, but with greater sparite proportion. These nodules are < 1% of the thin section.

Thin section 151: 24-32 cm.

This section is the abrupt contact between the A1 and the Y horizon.
For the A1 horizon, the description is as in the above thin section. Microstructure is exclusively granular in the contact, with granules having 100 to 190µmø. Very few mixing occurs between the two horizons.

Y HORIZON

MICROSTRUCTURE
Weak aggregation becoming moderate in the areas with plate aggregates. The aggregates, not fully developed, are plates in the 70% of the horizon thin section. Horizontal parallel orientation pattern. Their size ranges from 70µm to 1mm depth, and are several millimeters long. Rough under 100x magnification. Partially accommodated. In the 20% of the horizon section, the horizontal organization is interrupted by a kind of aggregation that can be described as massive or as rounded blocks with weak pedality. These areas have the most pure gypsum.
Voids: **Elongated interaggregate vughs.** The more typical width ranges from 20 o 200µm, but someone reach 1mm; they can be several millimeters long. Parallel horizontal orientation pattern.
Channels and chambers are less common, and are often occupied by radicohists or their residues. Sizes are variable, and can reach millimeter. Walls are like in the vughs, and when the section is longitudinal are vertical or inclined.
Microstructure of platy aggregates, and in a small extent of channels and chambers.

GROUNDMASS
Coarse material. None
Fine material: Gypsum lentils < 10µm. The mass has a dirty appearance because of the microsparite crystals that are irregularly sparse in the gypseous material.
b-fabric of the fine material: microcrystalline gypsic, with sparse carbonatic silt.

ORGANIC COMPONENTS
- **radicohists** or their residues in all decay stages. Some of them contain oblate excrements < 140µmø, or by fecal aggregates similar to those in the A1 horizon.
- **organic residues**, comminuted and dispersed in the groundmass. Neither red organic matter or spores' clusters appear.
- **hyphae** (6µmø) associated to organic residues. This kind of hyphae are rare in the groundmass, being more abundant filaments (<3µmø) that also occur within the lenticular microcrystalline gypsum nodules. These filaments can be easily seen in the walls of the horizontal voids, coincident or confused with the silty coatings, perhaps because the better visualization of the filaments in the aggregates' edges.

PEDOFEATURES

1.- **Microcrystalline lenticular gypsum nodules.** These nodules are 30% of the thin section, and they can be distinguished from the groundmass because they do not have carbonatic silt. They are pure crystalline nodules made by gypsum crystals whose size is in the limit of the optical microscope resolution.

The nodules are < 2mm, and can be seen naked eye in the thin section. The shape is rounded reentrant, and they have very distinct border with the surrounding material (microcrystalline lenticular gypsum with micrite). When the are large enough, they interrupt the horizontal voids pattern of the soil.

The nodules have their own voids pattern, irregular or elongated vughs < 100µm. The distribution of these vughs give to the nodules an appearance of composed by more yellow (parallel light) and in extinction (crossed polarizers) areas. The composed appearance slightly fads under crossed polarizers, but can be still detected both because the voids pattern and because the occurrence of bigger gypsum crystals related to those vughs. The small size of the crystals prevents to assert that they are gypsum recrystallization in voids.

2.- **Carbonatic silt coatings.** The coating of voids walls with silt sized carbonatic particles is frequent. The coatings occur either in the horizontal voids and in the channels and chambers. Sometimes occur as quasi-coatings, or are associated to gypsum coatings. Some thick coatings were detected close to fecal pellets made with groundmass of the A1 horizon.

No differences in composition or granulometry were observed in the coatings against the micrite sparse in the groundmass. As has been pointed out, the micrite in the groundmass has an irregular distribution, and in some places is concentrated producing opaque areas that could be described as intercalations, or that appear as coatings that became enclosed in the groundmass. The existence of gradations makes in many cases a convention to consider micrite as a constituent of the groundmass or as a pedofeature.

3.- **Lenticular gypsum.** Anhedral or imperfect lenticular crystals ranging from 25 to 90µm. They are < 2% of the section of the horizon. Their occurrence in the microcrystalline lenticular gypsum nodules is very rare, and only in the smaller crystal sizes. In the groundmass they occur as intercalar crystals, and use to be concentrated in specific areas. They often coat channels and chambers.

4.- **Infillings.** They are < 1% of the horizon section. Some chambers have a loose infilling of fecal pellets < 400µmø. One chamber contains three fecal pellets 1.3mmø each. In all cases the fecal pellets are composed by a material similar to the groundmass, i. e. microcrystalline lenticular gypsum, and they always contain carbonatic silt with a regular distribution, and never have pure microcrystalline gypsum.

Thin section 151 R

The section was made in a sample of the saccharoidal gyprock in the bottom (90cm) of the pit. In the field, the sample showed very slight evidences of alteration.

Under the microscope the sample was an alabastrine gypsum composed of non-uniform extinction components (c.e.n.u. in Spanish) and microcrystalline gypsum. The c.e.n.u. have variable sizes in the different areas of the thin section, and some of the c.e.n.u. are macroscopic. Some veins occur composed by fibrous gypsum with subparallel crystals transversal to the vein. Some of the bigger c.e.n.u. contain anhedral or subhedral anhydrite inclusions < 70µm. Some of the c.e.n.u. show euhedral indentations.

Anhedral and poorly sorted sparite crystals < 110µm appear (< 1%) on the described gypsum background. Some of the sparite crystals show sub-lozenge sections, attributable to cleavage. Micrite particles (2%) are distributed in all the thin section and concentrate in irregularly distributed areas, and occur as coatings either in some dissolution voids and in the external surfaces of the rock.

In one region of the thin section, 80% of the surface is a mixture of sparite and micrite, and the other 20% is gypsum in c.e.n.u. and veins. In close contact, another region appears having a nodular structure provided that the micritic material occurs in a network resulting in small cells occupied by gypsum in c.e.n.u.

One region in the border of the sample is made by a micritic material with opaque inclusions with a organic look. In this regions a quera occurs having the central channel partially filled with gypsum lentils < 90µm, that become yellow in plane light when diaphragm closes.

The contact between the micritic marly material and the alabastrine gypsum has big lentils (up to 900µm) in several differentiation stages. Some of these lentils can be described as intercalar in the micritic marl, without special b-fabric associated to the lentils.

3.1.2.4. SOILS ON HILLSLOPES ON GYPROCK WITH LUTITES

The gypsum strata have some interbedded calcilutites that occur in specific sites because of the general folding. Marly slopes are favorable for vegetation, and profiles have O-A-Cy or O-A-By-Cy horizon sequence. The By horizons have millimetric lenticular gypsum crystals in vermiform growths or grading to a more regular distribution, that can reach the stage of isles fabric. Lenticular gypsum in Cy horizons crystals are often larger (a few millimeters) than those in the By horizons. Moreover, in Cy horizons the structure of the marl is disturbed but can be still recognized.

Thin sections show very well developed queras in the micritic parts of the subsurface horizons. The features of the queras are superimposed on the marl layering. This layering can remain in the isles of non-gypsic material, and the orientation of the layering often differs from one isle to other, attesting the disturbance of the marl.

Information about soils in hillslopes with lutites.

The chesas contain sites where gyprock alternates with some noticeable amount of lutites. Pedogenesis in these sites is also controlled by the ubiquitous gypsum, and can produce deep soils. Repeated growth and dissolution of gypsum crystals and queras development were detected in the marls, with milling effects where mechanical action of gypsum crystals and chemical action (calcification and decalcification) of queras concur to the lutite's edaphization. When exposition and land use are favorable, these soils support the small and degraded forests of *Quercus faginea* Lam., that are the more complex vegetation that can be seen in the Ivorra area. The characteristics of the representative pedon (IB134) are displayed in Tables 26 and 27.

Table 26. Summary field description of pedon IB134.

Horizon Depth cm	Color	Structure Friability	Organic matter	Roots	C.fr. = Coarse fragments S.f. = Special features	Boundary
O1 0-1	7.5 YR 2/1 moist	Organic.		Very few, very fine vertical, alive.	C.fr.- None. S.f.- None.	Abrupt, smooth.
O2 1-3/5	7.5 YR 4/3 moist.	Organic.		Few, very fine horizontal, alive.	C.fr.- None. S.f.- None.	Abrupt, wavy.
Ay 3/5-28/35	10 YR 6/4 moist.7.5 YR 8/2 (spots).	Weak, fine granular. Friable.	Very few, well incorporated	Abundant, very fine to coarse, horizontal, alive.	C.fr. Frequent cobbles subangular-spheroidal, highly weathered gypsum. S.f.- Millimetric gypsum crystals in root channels and pores.	Diffuse wavy.

By 28-35/ 130↓	2.5 Y 5/2 & 2.5 Y 6/3 moist.	Weak very fine sub-angular blocky. Friable.	None.	Few, very fine to coarse, horizontal, less abundant in depth, alive.	C.fr.- Few, more coarse and less weathered that in the underlying horizon. S.f.- Abundant accumulations like the underlying horizon.	

Table 27. Analytical data of pedon IB134

Sample reference and horizon	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25°C
134/1 O1	0-1	7.1	44.1	5.7	2.5	2.01
134/2 O2	1-3/5	7.4	12.2	18.1	13.3	1.95
134/3 Ay	6-24	7.6	0.7	8.5	64.3	2.07
134/4 By	34-130	7.6	0.2	21.0	36.4	2.19

Reference	Particle size distribution				Exchange cations (cmol(+,-) / kg)				
	Sand		Silt 0.05-0.002 mm	Clay <0.002 mm	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC
	2-0.5 mm	0.5-0.05 mm							
134/1	-	-	-	-	-	-	-	-	-
134/2	-	-	-	-	-	-	-	-	-
134/3	13.75	40.54	34.12	11.59	12.8	2.80	0.10	0.10	15.80
134/4	15.32	11.39	51.92	21.37	-	5.40	0.20	0.15	-

Micromorphology of pedon IB134

Thin sections IB134: 0-7, and IB134: 0-9

Both thin sections are described together; the first one shows the O_1, O_2, and the first millimeters of the B_y horizons. The second thin section shows the lower part of the O_1 horizon, O_2 horizon, A horizon, and the 2 upper centimeters of the B_y horizon.

O1 Horizon.
Apedal, with 80% voids. The soil material is made with organ residues and other organic residues at several decaying stages. Hyphae are also common. Only exceptionally some mineral material appears, either as aggregates and as isolated crystals.

Soil material is almost grouped in excrements having four major types of shapes. Hyphae (6 to 12µm Ø) appear as a network between aggregates. Small (6µm) crystals, often twinned, appear within the best preserved organ residues. Loose gypsum crystals are rare, and always < 0.5mm.

O2 Horizon.

MICROSTRUCTURE

Strongly developed microstructure.

Most aggregates are granular, but the greater ones are crumby. Size ranges from 90 to 450µm, and are 25% of the surface. Some isolated sparite (100µm) and gypsum (50µm) crystals also appear. Organic material is 25% of the section, and voids are 50%.

Microstructure is granular and with organic residues.

GROUNDMASS

Coarse material

Quartz (25µm) within aggregates.

Mica flakes appear single as well as within the non-micritic aggregates. Maximum observed longitude was 50µm.

Micritic material, some (20µm) completely micritic aggregates can be considered as coarse material.

Anhedral sparite. These crystals are abundant, either isolated or incorporated into the groundmass of all kind of aggregates, even in those aggregates showing reticular striated b-fabric and decarbonated appearance. **Gypsum** (1%), the greater crystals seems to be coarse fragments in desaggregation.

Nodular sparite is rare, and only in some aggregates. Shell residues are also rare.

Fine material

The mineral aggregates are made by two kinds of fine material, one is micritic, and the other looks decarbonated. It is rare to have both kinds of material in the same aggregate.

ORGANIC COMPONENTS

These components appear as excrements showing a worst conservation that in the underlying horizon. Hyphae are similar but less abundant that in the above horizon.

PEDOFEATURES

Some sparite (<1%) appears within organ residues. The internal characteristics of these crystals are different from quesparite.

A Horizon

MICROSTRUCTURE

Moderately developed pedality. The upper aggregates are similar to 0_2 aggregates, and the proportion of voids and organic components decrease in depth. Granular structure passes in depth to vughy structure showing some dense irregular aggregates with reentrant edges, platy shape, and horizontal disposition.

The packing voids in the upper part gradually change into fissures between more and more accommodated aggregates. Some channels and chambers also appear, and in the lower part of the horizon, horizontal channels are predominant; these channels use to be occupied by decaying roots and fungi.

Microstructure of this horizon is granular or loose crumby in the upper part of the horizon, and becomes more compact in depth, with areas of spongy microstructure.

GROUNDMASS

Coarse material.

Quartz, <100µm, angular, unsorted, occurring in both the micritic and the decalcified groundmass.

Mica flakes <80µm long.

Micritic material. This material has two presentations, but all transitional forms also appear. The first presentation is as aggregates of a dense microsparitic mass, with some mica included. Most are complete and rounded aggregates, some of them with a decalcified area within the aggregate. The other presentation of the micritic material is with the shape and appearance of fragments of a sedimentary rock, containing quartzes, organic spots, and sparitic areas.

Anhedral sparite. This material looks like quesparite, and is abundant either isolated and within the aggregates, even in aggregates with decalcified groundmass. Quemosaics are rare.

Gypsum. The smaller fragments are difficult to distinguish from quartz, even if the more rounded shapes seems more common in gypsum. Some areas (<1%) have a concentration of separated gypsum crystals evidencing the existence of gypseous fragments (gypsorelics) in an advanced stage of alteration by dissolution.

ORGANIC COMPONENTS

Organic residues, most of them opaque radicohists with fungi. Some radicohists are phlobaphenized. Radicohist are horizontal. Excrements are less abundant than in the underlying horizon.

PEDOFEATURES

The aggregates with reticular striated b-fabric are not described as pedofeatures because these aggregates do not show their typic quevoid pattern, and often they are mixed with quesparite crystals. These features show that this material has been deorganized and mixed.

Some quemosaics have been preserved, and can be described as pedofeatures in spite that their crystals do not have the typical shape, and dissolution evidences can be observed.

The lower boundary of the horizon is distinct.

Thin section IB134: 1-9 (lower part)

MICROSTRUCTURE

Apedal. Most voids are channels and chambers and some fissures, and also some porosity due to the packing of the crystalline components -mainly gypsum lentils- can also be observed. The microstructure is of gypsum lentils packing, and some of channels and chambers. The isles of fine material are < 1% of the section.

GROUNDMASS

Quartz. Angular grains of quartz (<40μ) occur in the quedecal isles. These quartz grains are often difficult to distinguish from gypsum.

Mica flakes < 300μm long appear in the quedecal isles.

Gypsum. The greater gypsum crystals could be described as coarse material.

ORGANIC COMPONENTS

Organ residues, often associated with hyphae; Sporangia; Hyphae are common. Sometimes the fine hyphae are associated with microcrystalline gypsum.

PEDOFEATURES

The whole horizon is considered to be made by a gypsic fabric pedofeature. Several materials can be distinguished in this horizon:

1. **Lenticular gypsum.** This material is 50% of the surface of the thin section, and is in fact the groundmass of the thin section.The scarce porphidoblastic gypsum fragments can be described in this section together with the lenticular gypsum from 0.5 to 2 mm, whose greater specimens are imperfect lentils and include silt sized dust. All these materials seems originated in the underlying rock. All this gypsum is random distributed, moreover its effects on the pedon's behaviour are the same, thus has been described under the same section.
2. **Microcrystalline lenticular gypsum.** Its abundance is estimated in 10% of the thin section, even if often a continuity in sizes occurs with the coarse gypsum.This material shows areas of purer material, that produce compound nodules. This material is also related to voids (fissures or root channels), and to finer hyphae.
3. **Quesparite.** Single quesparite crystals are < 1%. Some local accumulations of quesparite can be seen, corresponding to quemosaics with separated crystals.
4. **Isles of fine material.** 1% of the thin section. The size of these isles is always < 1 mm. Most isles look as quedecal material, but the composition is difficult to establish for the smaller isles. Some of the isles associated with the bigger gypsum lentils show weak birefringence in the interface with lentils.
5. **Carbonatic silt.** Particles (3 to 8 μm) dispersed in the gypseous groundmass, between the gypsum lentils or irregularly grouped, sometimes related to voids. These particles are identical to the inclusions within the greater gypsum crystals.

In the thin section IB 134: 11-19, two parts can be distinguished naked eye: the upper (11- 16.5), and the lower (16.5-19), that are described separately.

Thin section IB 134: 11-19-up (11-16.5).

The 65% of the thin section is made by randomly packed crystals, mostly (60%) gypsum. A small proportion of this gypsum could be described as coarse material because of the evidences of diagenesis, the sizes (>1 mm), and the dissolution shapes. The most abundant is the gypsum having imperfect lenticular shapes, biphasic growths, and included carbonatic silt. Besides this, other gypsum show typical lenticular shapes and slightly smaller sizes, and is assumed to be pedogenic, as well as its gradations to microcrystalline lenticular gypsum. All these kinds of gypsum grains show gradational forms, and are random packed.
The behaviour of all gypsum in the thin section is assumed to be the same, and it is practical to describe it as a gypsic fabric pedofeature.

MICROSTRUCTURE
A 5% of the section is occupied by fine material isles. The bigger isles are millimetric and under the microscope their material is the same that the underlying marl. These isles use to be associated with gypsorelics and with residues of queras. Most of the smaller isles are quedecal residues.
Voids (30%) are of crystals (65% gypsum and some quesparite) and fine material isles (marl and quedecal residues) packing.
The isles microstructure is massive or weakly fissured, whereas in the gypsic fabric pedofeature the microstructure is mainly single granular (crystals).

GROUNDMASS
Coarse material.

Quartz, <60%, rare, difficult to distinguish from gypsum.
Mica. Very few flakes, most of them < 35μm, exceptionally up to 120μm.
Opaque spots, organic. Rare.

Fine material.

Some micritic isles have colour, cristallitic b-fabric, and other internal characteristics very similar to the calcilutite underlying the pedon. Other isles having the b fabric reticulated strial or speckled are quedecal residues, even if quevoids are not frequent.

ORGANIC COMPONENTS
Organ residues and a couple of sporangia within isles of fine material.

PEDOFEATURES
1. **Gypsic fabric** pedofeature. This feature is made by a loose packing of gypsum crystals. Also a2% of the section is made by spheroidal-rounded or irregular masses (Ø < 0.6 mm) of microcrystalline lenticular gypsum. Quesparite (1%) appears as single crystals and some transitions to quemosaics. Fine material (1%) is silty single grains, in transition to isles. Some silt is similar to the silt included in the gypsum lentils, other silt is similar to the silt in the quedecal.
2. **Gypsic features** in the fine material isles. The gypsum crystals are in general lenticular, and often occur as intercalar in the fine material isles. A gradation can be observed to infillings and to gypsum belonging to the gypsic fabric pedofeature; often the isles have a size similar to the gypsum lentils.
3. **Queras.** No complete queras have been observed. Quedecal has a high degree of fragmentation, and quevoids are rare, but often contain intercalar gypsum lentils. Quemosaics show all the decaying stages, up to single quesparite grains, In some cases, the cellular envelopes are preserved.

Thin section IB 134: 11-19-low (16.5-19).

MICROSTRUCTURE
Weakly developed pedality. Voids are concentric fissures and some channels. Several areas show vughs from 0.5 to 1.5 mm in size. Other voids results from the packing of gypsum crystals. Microstructure is dominated by concentric fissures; microstructure is vughy between the fissures.

GROUNDMASS

Coarse material.

One of the isles of fine material (2 mm Ø) is similar to the isles in the thin sections IB 134: 11-19, and IB 134:11-16.5). All the other coarse material is made by pedofeatures, and so are considered the few (<<1%) of coarse (2 mm Ø) gypsum grains.

Fine material.

Most fine material is silt sized, with a carbonatic look, but some mica flakes can also be seen. Fine material is dispersed among the gypsum and quesparite crystals, and in some areas fine material appears only coating the gypsum lentils. In some areas the related distribution of the big gypsum lentils is chitonic, and in some areas becomes porphyric.

ORGANIC COMPONENTS

Roots residues are <1%. Hyphae (<1%) are associated to roots residues or to microcrystalline gypsum.

PEDOFEATURES

1. **Gypsum** is 80% of the described section. All the varieties below described show transitional forms. Most gypsum is random packed, but lenticular gypsum shows a concentric disposition, parallel to fissures. Crystalline gypsum (75%). Under this denomination are included all the lenticular or quasi-lenticular shapes, and the few cases (<1%) of gypsum of rocky origin, that always are coarse fragments in an advanced degree of desaggregation. Microcrystalline lenticular gypsum (5%). Rounded or irregular masses with a modal size of 0.2 to 0.5 mm, exceptionally reach 1 mm. The crystals that compose these masses are often 8μmfi in size and the colour under plane light is only faint yellow. In some areas these masses coalesce, including the other constituents.
2. **Queras.** Quesparite crystals packed with the other constituents is 2% of the section. Few desaggregated residues of quemosaics can be seen. Dissolution shapes are frequent in quesparite crystals.
3. **Coatings.** Gypsum coatings (1%) in the voids' walls have the crystals with a radial distribution pattern. Silty-clayed material dispersed throughout all the section, appears as a coating of gypsum lentils in some areas; some of these coatings show a weak birefringence.
4. **Loose incomplete infilling** in one channel. The infilling is made by aggregates (15 μm Ø), some of them of micritic material, and the other of microcrystalline gypsum crystals mixed with roots residues and gypsum crystals. The concentric pattern of the fissures and the concentric disposition of the gypsum lentils suggest a faunal origin for this part of the thin section.

Thin section IB 134: 18-26.

MICROSTRUCTURE

Apedal. Sub-horizontal fissures (20%), mainly affecting some fine material isles; some channels and chambers also appear. The other voids result from the complex packing of crystals (gypsum and quesparite) and fine material isles. Isles fabric.

GROUNDMASS

Most (65%) of the soil material in this thin section are pedofeatures (mainly gypsum and quesparite). The groundmass is lenticular gypsic.

The fine material isles (15%) could also be considered pedofeatures because of their submillimetric size. Moreover, all the isles have a quedecal area, that is often in contact with a quemosaic in desaggregation and incorporating the quesparite crystals into the gypsic fabric pedofeature.

The groundmass of the fine material isles is described as follows:

Coarse material.

Quartz, 5% of the isles surface, angular, 60 to 120μm. The abundance is the same in the micritic areas than in the quedecal areas.

Micas, 1%, modal size of the flakes is 80μm, maximum size is 190μm. Mica flakes are more visible in the quedecal areas.

Fine material: Crystallitic b-fabric in the areas other than quedecal. Porphyric c/f related distribution.

ORGANIC COMPONENTS
Roots residues (<1%). Hyphae (6 µmØ) associated to the roots residues.

PEDOFEATURES
1. **Gypsic fabric pedofeature**. All gypsum is 55% of the thin section. Crystalline gypsum (50%). This denomination includes all the more or less lenticular gypsum together with some (<1%) millimetric gypsum fragments, that always show voids and dissolution traces. Some of these fragments have evidences of rocky origin. Microcrystalline lenticular gypsum (5%). Irregular rounded masses, often with compound look, and that can reach 1.8 mm. The most common masses have the bigger lentils, and their yellow color is faint. Some of these masses are associated to voids, some times as coatings.
2. **Gypsic features** in the fine material isles. Some (<1%) lentils (300 µm)occur as intercalar in the quedecal areas of the fine material isles.
3. **Queras.** Quesparite (10%) occurs as more or less desaggregated quemosaics. Single quesparite crystals are rare. Most of these residues of quemosaics are in close contact with the quedecal areas of the isles. This quedecal material do not occur separated from the micritic material of the isles, and does not have quevoids. These features allows to describe this material as a part of the fine material isles.
4. **Coatings.** Gypsum coatings in channels are rare (<1%).

Thin section IB134: 37-45.

MICROSTRUCTURE
Apedal. Some fissures appear, affecting only to the fine material isles. Voids are also of open packing of gypsum crystals, quesparite and fine material isles. All voids are 35% of the thin section. Isles fabric.

GROUNDMASS
Millimetric fine material isles (up to 4 mm) are the 15% of the thin section. Queras are more preserved than in the above thin section (IB134: 18-26), as is show by the micritic and quedecal material with quevoids and quemosaics.
Coarse material.

Quartz (1% of the isles section). Subrounded grains from 60 to 120 µm. Their non homogeneous distribution suggests two different parent materials; moreover quartz grains seem to be more abundant in the quedecal areas.

Mica flakes are similar to the above thin section, but less abundant.

Fine material. Crystallitic b-fabric.

ORGANIC COMPONENTS
Root residues (<1%), in advanced decaying. Some of these residues have red ellipsoidal excrements (15µm Ø) from oribatid mites.

PEDOFEATURES
1. **Gypsic fabric pedofeature**. All gypsum is 40% of the thin section. **Crystalline gypsum**: The big lentils are more abundant than in the above (IB 134: 18-26) thin section. **Gypsum fragments** are less abundant than in the above thin section, but the other characteristics are similar. **Microcrystalline lenticular gypsum**: Only some traces of irregular masses were seen.
2. **Gypsic features** in the fine material isles. Some intercalar gypsum lentils (<1%). The intercalary lentils in the quedecal are smaller than those in the limolitic material.
3. **Queras.** Quesparite is 10% of the thin slide, most quesparite belongs to quemosaics, that are better preserved than in the above thin section. The association of quemosaics with the quedecal material is more evident in this thin section than in the above one (IB 134: 18-26).

Thin section IB 134: 70-78.

MICROSTRUCTURE

Apedal. The aggregates (60%) are subangular fragments of lutite (2 to 5 mm). They are accommodated in some areas. Voids are 10% of the thin section, the most common are subhorizontal fissures, but also occur packing voids of gypsum crystals and lutite fragments. Some chambers appear in the lutite. The microstructure is subangular blocky.

GROUNDMASS

Lutite is 60% of the thin section, and has a reddish , micritic or microsparitic mass, with opaque spots from 4 to 30µm size. Some zones are more translucent, and opaque spots, mica flakes and quartz grains are abundant. Zonation is due to discontinuous and mixed strata 0.5 cm thick.
Gypsum is 30% of the thin section. Most gypsum occurs as crystals greater than 1 mm, sometimes with composed appearance due to their micritic inclusions. Smaller crystals also appear. Most gypsum occur between the lutite fragments; the intercalar gypsum looks from rocky origin. The distinction between gypsum fragments with advanced diagenic facies, and the gypsum from sediment is difficult.
Celestite (<<1%) appears either in lutite voids and in area of the lutite showing a desaggregated appearance. Some celestite crystals can also be found included in gypsum crystals.

ORGANIC COMPONENTS

Radicohists (<1%) with phlobaphenized or with opaque areas in the contacts between strata.

Thin section IB134: 130-138.

Apedal. Voids (10%) are horizontal and vertical fissures, and some chambers. The stratification of the same materials described in the above thin section (IB 134: 70-78) is well preserved. Gypsum (25%) occurs mainly in the contacts between the strata, and sometimes as intercalar. The most abundant gypsum is lenticular, concentrated in the contacts of the strata and in those strata with coarser granulometry. Some gypsum looks as compound, due to the micritic inclusions.
Celestite is similar to the above thin section (IB 134: 70-78).
Roots residues (<< 1%) in advance stages of decay.

3.1.2.5. SOILS ON SADDLES AND STABLE FOOTSLOPES

Photointerpretation and field inspection suggested that some saddle positions can be stable, in the framework of the general erosive dynamics of the chesas. After the study of several pits in these positions, different stages of development of calcic horizons were found, ranging from calcic nodular horizons to continuously cemented calcic horizons. The nodules are micritic, and the sharpness of their separation from the groundmass differs by horizon. The field description was confirmed by micromorphology, that also showed that the micritic nodules contains voids with microorganisms.

Calcic nodular horizon were later identified in basal positions of stable north-facing footslopes. The calcic horizons lie immediately below the A horizons. The gypseous horizon appears under the calcic horizon.

All soils with calcic horizons studied in Ivorra area have a dense vegetation of *Quercus faginea Lam.*, *Q. coccifera* L., *Rosmarinus officinalis* L., *Ononis tridentata* L., *Genista* sp., and *Thymus* sp.

Cultivated soils with calcic horizons underlying gypseous horizons were found in stable positions of the western part of the chesa, out of the Ivorra area.

Information about soils on saddles

All the studied pedons with calcic endopedon in Ivorra hold forest or shrub dense vegetal cover. Other common feature is the good structure of the A horizon and the absence of gypsum in the calcic endopedon that overlies the gypseous endopedon. This absence was detected during the field study of soils, and confirmed both by micromorphology and by chemical analyses (Tables 28 and 29, representative pedon IB135).

Thin sections allowed the identification of several stages of development of the calcic nodules, according to their composition and to the degree of differentiation against the surrounding groundmass. Specific microorganisms related to the nodules were also detected.

Table 28 Summary field description of pedon IB135.

Horizon Depth cm	Color	Structure Friability	Organic matter	Roots	C.fr. = Coarse fragments S.f. = Special features	Boundary
O1 0-2	10 YR 2/3 moist	Organic.			C.fr.- None.	Abrupt smooth.
A1 2-18	10 R 5.5/3 moist. 10 YR 7/3 dry.	Primary moderate fine subangular blocky; secondary granular - Friable	Common well in-corporated	Abundant, very fine to medium, vertical, alive.	C.fr.- None. S.f.- None.	Clear smooth.

Bwkn 18-44	7.5 YR 5/3 moist.	Primary moderate fine subangular blocky; secondary granular. - Friable	Few.	Common very fine to medium, horizontal, alive	C.fr.- None S.f.- Fine calcium carbonate nodules.	Diffuse smooth.
By 44-140I	10 YR 5.5/3.	Very weak fine, subangular blocky and associated medium platy. - Friable.	None.	Few, very fine to coarse horizontal, alive.	C.fr. None. S.f.- Abundant vermiform gypsum in channels	

Table 29 Analytical data of pedon IB135

Sample reference and horizon	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25°C
135/1 O1	0-2	7.6	19.5	22.9	0.3	1.34
135/2 A1	2-18	7.5	3.2	32.8	0.4	0.59
135/3 Bwkn	18-44	7.8	1.3	37.8	0.3	0.24
135/4 By	44-140	7.5	0.3	16.9	41.9	2.07

Refe-rence	Particle size distribution				Exchange cations (cmol(+,-) / kg)				
	Sand		Silt 0.05-0.002 mm	Clay <0.002 mm	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC
	2-0.5 mm	0.5-0.05 mm							
135/1	-	-	-	-	-	-	-	-	-
135/2	1.21	18.29	42.82	37.68	9.10	3.20	0.10	0.30	12.70
135/3	1.44	11.21	54.10	33.25	8.60	3.50	0.10	0.20	12.40
135/4	5.86	28.90	flocculate	flocculate	11.00	2.10	0.15	0.10	13.35

Saturated paste						
Sample reference	Hs (%)	CEe dS/m 25°C	mmol(+,-) / l			SAR
			Ca^{2+}	Mg^{2+}	Na^{+}	
135/1	127.8	2.98	33.3	12.3	1.0	0.2
/2	45.6	1.70	17.8	6.4	1.0	0.3
/3	72.2	1.03	11.4	3.0	1.0	0.4
/4	30.0	2.50	30.3	7.6	1.0	0.2

Micromorphology of pedon IB135.

Thin section IB135: 0-3.5

The O horizon is made by horizontal organic residues and by some fecal pellets also made of plant residues with high degree of comminution. Another kind of excrements are oblate (<80µm), made of organic amorphous material, and usually occur within the more degraded organ residues. Hyphae (6µmø) are smooth and usually associated to organ residues; other hyphae (3µmø) are ornamented.

MICROSTRUCTURE
The A horizon has some big vughs, as well as planes and channels and chambers. Microstructure is complex of faunal activity, and subangular blocky in a minor extent. Faunal work is concentrated in the top, whereas compaction is more evident in depth.

GROUNDMASS
Sand fraction (15%) is mainly sparite with modal size of 50-100µm. Some micritic nodules of 300µmø occur. Crystallitic b-fabric. Related c/f distribution is porphyric.

ORGANIC COMPONENTS
Black and opaque plant residues are abundant, some of them are phlobaphenized and also some spots (30µmø) occur. Hyphae are abundant in connection with vegetal residues.

Thin section IB135: 3-11.

MICROSTRUCTURE
Strongly developed pedality. Subangular blocks (1 to 3mm) in the 70% of the section, accommodated.Interaggregate craze planes and some channels and chambers. Irregular and elongated intraaggregate vughs (< 80µm), and chambers (< 300µm) often with roots residues. Complex microstructure of subangular blocks and of channels and chambers. Some aggregates are thinly fissured.

GROUNDMASS
Coarse material.

Quartz (<5% of the section), unsorted, from 20 to 150µm.

Mica (<1% of the section), from 40 to 50µm.

Micritic nodules (5% of the section) the common size ranges from 90 to 600µm, but someone reach several millimeters. The shape is rounded, but the greater are more irregular.The greater nodules contain quartz grains, sparite crystals, micas and opaque materials, all randomly distributed. The medium sized nodules have a microsparitic or sparitic core. Sometimes the nodules are halo-nodules, that can be described as impregnative of the groundmass. Most nodules are in continuity with the surrounding groundmass, but the greater nodules are always separated from the groundmass by a void.

Sparite. All types of sparite occur, always in the groundmass and not in voids. Anhedral or subhedral sparite (15% of the section), from 50 to 120µm, moderately sorted, often reentrant edges, rounded. Most of the anhedral sparite looks like quesparite because of the fine strokes with fan disposition, and because their iridescence in crossed polarizers, the others show cleavage lines or are polycrystalline. Euhedral sparite (2% of the section) from 300 to 600µm, with cleavage lines and dissolution evidences in these lines. Nodular sparite (<1% of the thin section), from 400 to 800µm. The bigger are more oblate and have reentrant sinus that can remain voids or be incompletely filled with groundmass. Some nodules have a sparitic core and a micritic halo.

Fine material. Highly carbonatic; crystallitic b-fabric. The related c/f distribution is porphyric.

ORGANIC COMPONENTS
Organ residues, mainly roots in different decay stages. Other organ residues are phlobaphenized. Sporangia occur as spheres (80µmø) with alveoli (6µmø); spores also appear in the groundmass.
Hyphae (<8µmø) in the voids and in opaque organ residues.

PEDOFEATURES
The micritic nodules described as groundmass are not considered pedofeatures because the bigger ones seem to be inherited. Some few areas with quesparite accumulation are not considered textural features but deformed pedofeatures, i.e. queras in the decaying way. Some organic residues highly decomposed and incorporated into the groundmass are considered as pedofeatures.

Thin section IB135: 16-24.

MICROSTRUCTURE
Strongly developed pedality, subangular blocks from 3 to 6mm, rough under 40x. Accommodated only in the small voids. Interaggregate craze planes, and channels and chambers. Intraaggregate vughs that can be irregular (100µm) or very elongated; also some intraaggregate chambers with roots residues occur. Complex microstructure of subangular blocks and some of channels and chambers.

GROUNDMASS
Coarse material.

Quartz and mica similar to the thin section IB135: 3-11.

Anhedral or subhedral sparite crystals (5%) similar but more sorted than in IB135: 3-11. These crystals are more abundant in the aggregates that seems more recent because are associated to channels and contain more organic residues. Obviously, these crystals could also be described as pedofeatures, but because the good incorporation into the groundmass, and the scarcity or absence of complete queras, it seems reasonable to consider them as groundmass. Moreover, in the bottom of this thin section complete queras occur. Euhedral crystals (1%) are similar to the above thin section.

Nodules (< 1%), well sorted, dissolution voids are rare.

Fine material. Similar to the above thin section. Crystallitic b-fabric. The related c/f distribution is porphyric.

ORGANIC COMPONENTS
Similar to the above thin section, only the differences are described here. Organ residues and hyphae are less abundant than in the above thin section. Grouped spores (8µmø) connected to hyphae occur within the micritic nodules.

PEDOFEATURES
1.- **Micrite.** Three presentations of the pedogenic micrite are described, but all transitional forms can also be found.

1a.- **Separate nodules** (20% of the thin section surface). The biggest is 10mm x 5mm is a nuclei nodule (= pisoid), with a nucleus of denser micrite. This core is darker in plane light, the limits are diffuse, and has less pores than the envelope. The core contains angular quartzes and calcitic phantoms of pelletoidal structures. The envelope has different color, and brown organic matter that is absent in the core. Fantods are scarce and faint. Vughs are parallel to the nucleus edges, and in the interior walls of the vughs the micrite crystals are coarser than the average. Hyphae and spores are more visible in the cracks and in the more transparent areas of the micrite. Single spores are rare, and no spores were observed in the core, only some organic residues that could be spores residues.

1b.- **Nodules integrated** in the groundmass (5% of the thin section surface).

1c.- **Nodules impregnative** of the groundmass (15% of the thin section surface). Some of them are vughy.

2.- **Queras.** Only some individuals occur in the bottom of the section (1% of the thin section surface). Some concentrations of quesparite crystals within aggregates containing organic residues occur in areas showing structure from biological activity. These concentrations can be qualified as queras residues in an advanced stage of incorporation into the groundmass.

3.- **Loose infillings** of channels. Infillings are a mixture of comminuted organic residues, several kinds of deformed excrements (< 700µmø), and groundmass fragments.

4.- **Organic spots**. The amorphous organic material in spots is less abundant than in the above thin section.

Thin section IB135: 30-38.

MICROSTRUCTURE
Moderately developed pedality. Aggregates (75%) are subangular blocks. Two voids patterns occur. The first one is associated to the no-micritic areas, and is characterized by millimetric channels and chambers, and some vughs that can result in a locally granular structure. The other pattern occurs in micritic areas, and is characterized by planes with slight horizontal trend, and some vughs. The whole section is slightly affected by craze planes. Microstructure is complex of channels and chambers and fissures. Very weak structure of subangular blocks.

GROUNDMASS
Coarse material.

Quartz and mica are similar to IB135: 3-11.

Anhedral or subhedral sparite (5% of the thin section surface). Most of these crystals occur in the vughy areas. Well sorted. Their consideration as pedofeatures can be discussed as in the thin section IB135: 16-24. Euhedral sparite similar to the above thin sections.

Spheroidal micritic nodules are scarce, and similar to IB135: 16-24.

Fine material.

Similar to the above thin section. Crystallitic b-fabric. The related c/f distribution is porphyric.

ORGANIC COMPONENTS
Organic components are similar to the above thin section, but more scarce and with a more advanced decay.

PEDOFEATURES
1.- **Micrite.** Separate nodules do not occur. The integrated nodules are smaller and scarcer than in the above thin section IB135: 3-11. The impregnations of the groundmass are similar to the above thin section but much more developed (30%), and the shape is more irregular and the edges more diffuse.
2.- **Queras.** They are 15% of the thin section, being less abundant in the micritic areas. They are irregularly distributed, and seem to be superposed. The presence of quefe is not general. No decaying queras occur, and the quesparite crystals incorporated into the aggregates are described as groundmass.
3.- **Loose infillings** of channels. Discontinuous infillings of groundmass fragments (including micritic material) and comminuted organ residues.
4.- **Amorphous organic material.** Spots randomly distributed in the groundmass and quedecal.

Thin section IB135: 61-70.

MICROSTRUCTURE
Apedal. Isles (45%) with section of subangular blocks, centimetric, rough, slightly accommodated, and weakly horizontals. The interisles voids pattern is a complex crystal packing. The intraisles voids are channels and chambers, and some isles show frequent lenticular-shaped voids.
Isles fabric. The structure of the gypsic part is a single grain (crystal) structure. The silty-clay material (groundmass of the isles) has a general fissure structure, with areas of channels and chambers structure because of the queras superposition and faunal activity.

GROUNDMASS
Coarse material.

Poorly sorted **quartz** (2% of the isles section surface). Mica, euhedral sparite (120 to 300µm), and spheroidal nodules are < 1% each.

Calcilimolite (< 1%) in rounded fragments (0.5 to 2mmø). These nodules are made by subhedral carbonatic crystals (75%), and opaque or brown spots (15%); the remaining 10% is quartz and silicatic minerals. Some are fissured or show desaggregation symptoms. One of these nodules is attacked by a quera.

Fine material.

Similar to the above thin section. Crystallitic b-fabric. The related c/f distribution is porphyric.
Traces of special b-fabrics are associated with some gypsum lentils.

ORGANIC COMPONENTS
These components are < 1% of the thin section surface. Organ residues in queras or in channels infillings. The opaque or brown spots (60µmø) appears in groundmass and in quedecal, and are less frequent in the gypsic mass. The greater spots are elongated(<300µm long) and angular, and only occur in the groundmass.

PEDOFEATURES
1.- **Lenticular gypsic fabric pedofeature.** This feature is made by a random packing of gypsum lentils. In most surface of the thin section the lentils do not touch each other, and only locally appear in contact or shows some ordered distribution. Other materials considered as pedofeatures of the lenticular gypsic mass occur mainly between the lentils, and sometimes included in the lentils. The modal size of the gypsum lentils is about 450 x 210µm, the greater are > 1mm. Other common size is 20-90µm, but the two sizes of lentils show few mixing. Lentils are 90% of the lenticular gypsic fabric pedofeature. **Radial and palisade gypsum** occur in small groups superposed in a micritic mass with desaggregation evidences. **The microcrystalline lenticular gypsum** (<1% of the thin section) do not show the typical yellow color, and occurs related to some root residues or in areas between queras. **Single quesparite crystals** are not too frequent if compared with the abundance of queras in this thin section. Most quesparite crystals are grouped in quemosaics. **Euhedral sparite** (<1%) show cleavage and dissolution evidences. They are coated by groundmass. **Celestite** (<1%) are elongated crystals <60µm long, with dissolution traces. It only appears in groups random packed. Some celestite crystals are included in gypsum lentils. **Fine material**: a gradation appears from single unidentified crystals to aggregates. In these aggregates the differences between micritic mass and decalcified mass (quedecal) are easy to detect.
2.- **Gypsic features in the isles.** Gypsum coatings are frequent in the chambers and in some planes. In some cases, these coatings are juxtaposed with carbonatic silt coating coatings. Some chambers are completely filled by gypsum. Intercalary gypsum lentils are frequent in some isles, with as much as 50% of its section. The more micritic are the isles, the less frequent is the intercalar gypsum. Some faint traits of b-fabrics associated to the lentils were observed only in the quedecal. Intercalar gypsum is rare in those isles having lenticular voids. The morphological traits and the disposition of the lentils continue in the quedecal areas.
3.- **Queras.** All the groundmass contains queras (15%), but they are scarce in some micritic aggregates. Some decalcified regions have channels and chambers structure, due to the concentration of queras. The advanced stages of queras decay are rare, and the radicohists are in advanced degradation. Quefe can be distinguished in few queras.
4.- **No separate nodules** occur, and the few integrated nodules have a destruction appearance.
5.- A centimetric chamber has a **loose discontinuous infilling** of fecal pellets and comminuted organic material. Quesparite crystals are frequent in the infilling. Gypsum lentils occur in the infilling and as chamber coating. The chamber cuts several queras.
6.- **Organic amorphous material.** The opaque or brown spots are described as organic components.

3.1.2.6. SOILS ON VALLEY BOTTOMS

The bottom of a typical *val* is flat, but can have considerable slope in longitudinal sense. In large gyprock areas, in the center of the Ebro basin, these *vales* can be several km large and tens of km long, with longitudinal slopes decreasing towards the outlet. In the Ivorra area all dimensions are smaller, and as we deal with the upper ends of the *vales*, the longitudinal slopes are considerable.

The flat bottom is made up of silty-loam or loamy gypsum-rich Holocene deposits derived from slopes. Archaeologists believe that the *vales* in the Ebro basin suffered several phases of erosion and filling (Peña et al., 1996). The *vales* bottoms are often cut by a ravine with sheer walls (Fig. 12), which is functional only after storms. In the Ivorra area, as in most gypseous lands of the Ebro basin, the *vales* bottoms are the main agricultural lands and have been subject to special practices to allow ploughing and to combat erosion.

In past times farmers built stone walls transversal to the valley bottoms, in order to gather water and sediments and to prevent the beginning or the upward advancement of a ravine. Most walls either cannot be conserved because of the rural exodus, or had to be destroyed to merge plots when years ago small plots became uneconomic due to the introduction of tractors and to the shortage of manpower that produced the abandonment of almond and olive trees. The size, shape and high longitudinal slope of the resulting plots forces the tractor to go by maximum slope lines, avoiding ploughing by contour. In these conditions, the formation of gullies is guaranteed if even a small storm occurs before coverage by the cereal. The concentration of runoff would be catastrophic, and careful maintenance of the interception trenches bordering the plots along the contact between footslope and the valley is a must. For this purpose, the products of slope weathering that are deposited on the footslope are mounded by farmers along the trenches. The farmers also preserve their agricultural area by filling the incipient gullies with the same materials.

The above factors contribute to the fluventic characteristics of the soils on the flat bottoms of the *vales*. Runoff and mudflow from slopes are the main suppliers of materials containing all the types of gypsum crystals and relic pedofeatures that are present in the upper soils. The appearance of all these components under the microscope as a disordered mixture can be understood in the context of their origin.

At the bottom of the valleys, the pedons are generally more than 2 m deep, with Ap and By or Ap and 2By horizon sequences. In ploughed *vales*, especially if the slopes are deforested, the shallow horizon (Ap) contains coarse gyprock and marl fragments. Rounded or subangular masses of microcrystalline gypsum appear too. Complete queras do not appear in thin sections, but their residues are frequent. Quesparite grains (Herrero and Porta, 1987), occur single or as mosaics under the microscope.

The strongest horizonation was found at the bottoms of non-cultivated *vales* whose slopes are well forested (pedon IB138). In thin sections, the gypsum appears (i) as lenticular crystals infilling or coating voids and (ii) as a pedofeature of gypsic fabric which often becomes (iii) isles fabric. Queras are more or less abundant but are well organized, and quesparite in the groundmass is rare. Microcrystalline gypsum is also rare (< 1%) and appears only in small (< 0.5 mm) masses associated with voids.

The morphology of lenticular gypsum in By horizons is very similar in all the landform units. Gypsum occurs in the field as vermiform or as a powdery massive horizon which is gritty to the touch, often with many of its gypsum crystals larger than 1 mm. The massive horizons either have isles fabric or a lenticular gypsum groundmass. Horizons consisting only of lenticular gypsum have not been observed in this area.

Information about soils in valley bottoms

Two sequences of pedons were studied in valley bottoms of Ivorra area. The first sequence is in the main valley cultivated since time immemorial, and having some transversal walls in the upper part. From the higher to the lower position the pedons are: IB145, IB142, IB137, and IB140. The second sequence is in a smaller secondary valley, the upper pedon is IB144 in a field that was leveled and filled 50 years ago, and the lower pedon is IB138 in the outlet on the main valley that was abandoned at least 20 years ago.

The low gypsum content in the A horizon of pedon IB138 is one of the most relevant features of the advanced horizonation in this pedon, contrasting with the cultivated soils in the bottom of vales. Further studies in the chesas, outside of Ivorra, show the same feature in those vegetated bottoms of vales.

Characteristic of a representative profile for the vegetated vales are presented in tables 30 and 31. For cultivated vales the data are in tables 32, 33, 34 and 35.

Table 30 Summary field description of pedon IB138.

Horizon Depth cm	Color	Structure Friability	Organic matter	Roots	C.fr. = Coarse fragments S.f. = Special features	Boundary
A11 0-16	10 YR 3.5/3.	Primary moderate subangular blocky fine; secondary weak, fine granular (faunal). - Friable.	Common well incorporated.	Very fine to medium common vertical alive	C.fr.- Common gravelly, tabular-subangular calcareous, non oriented.	Abrupt smooth
A12 16-83	10 YR 3/3 moist 10 YR 6/3 dry.	Primary strong, fine subangular blocky; secondary strong, fine, granular (faunal). - Friable.	Few, well incorporated.	Very fine to medium, few, horizontal, alive	C.fr.- Vughs with white coatings. S.f.- Abundant, vermiform gypsum in channels	Abrupt smooth
2By 83-173!	10 YR 3/3.	Very weak, fine subangular blocky. - Very friable.	None.	Fine and medium, few horizontals, alive and death.	C.fr.- None. S.f.- Abundant, vermiform gypsum in channels.	

Table 31 Analytical data of pedon IB138

Sample reference and horizon	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25°C
138/1 A11	0-16	7.4	4.6	39.1	0.4	0.19
138/2 A12	20-40	7.7	3.0	64.2	0.4	0.19
138/3 A12	60-83	7.7	4.0	35.9	0.1	0.26
138/4 By	83-170	7.7	1.1	17.1	57.8	2.19

Reference	Particle size distribution				Exchange cations (cmol(+,-) / kg)				
	Sand		Silt 0.05-0.002 mm	Clay <0.002 mm	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC
	2-0.5 mm	0.5-0.05 mm							
138/1	2.76	20.42	47.34	29.48	11.1	2.8	0.10	0.4	14.40
138/2	4.35	18.86	50.49	26.30	8.2	3.5	0.10	0.2	12.00
138/3	0.42	14.40	48.02	37.16	9.1	2.8	0.15	0.2	12.25
138/4	9.65	27.54	53.26	9.55	7.3	3.8	0.15	0.1	11.35

Saturated paste										
Reference	Hs (%)	CEe dS/m 25°C	mmol(+,-) / l							SAR
			Ca^{2+}	Mg^{2+}	Na^{+}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
138/1	47.4	1.38	12.0	3.0	0.2	Ip	11.0	5.0	0.8	0.1
138/2	42.4	0.74	6.0	Ip	0.8	ip	3.7	3.0	0.6	0.5
138/3	48.0	1.01	5.0	5.0	0.4	ip	4.2	5.5	1.2	0.2
138/4	41.4	2.66	30.0	5.0	0.6	ip	2.2	35.2	0.6	0.1

Micromorphology of pedon IB138

Thin section IB138: 0-4

MICROSTRUCTURE
Two horizons with different microstructure can be distinguished: from 0cm to 1.5/3cm, and from 1.5/3cm to 4cm.
0-1.5/3cm. Strongly developed pedality. Granular aggregates 2mmø rough under 100x unaccommodated. Simple packing voids. Granular microstructure.
1.5/3-4cm. Strongly developed pedality. Subangular blocks 3mmø, rough under 100x, accommodated. Interaggregate planes, some of them are horizontal; channels and chamber in a minor proportion. Intraaggregate channels, most of them with radicohists. Some aggregates are vughy. Complex microstructure of subangular blocks and vughy; also weak channels microstructure.

GROUNDMASS
Coarse material
quartz 1%, its maximum size is 800µm. Angular and ellipsoidal-subangular. The biggest quartzes are

spheroidal and polycrystalline.
micas, very rare.
micritic material 5%, unsorted fragments of calcilimolite, rounded-spheroidal. The most common dark-red spots, and another kind of fragments, more rounded, have their crystallites in desaggregation. All micritic material is described here because is supposed not of pedological horizon.
sparite 7%. Some are iridescent, subrounded-spheroidal, looking as quesparite and randomly distributed in the groundmass. Other crystals are euhedral, with cleavage in lozenge, and in general not iridescent. Transitional crystals also appear, as well as polycrystalline elements with euhedral contacts.

Fine material crystallitic b-fabric.

ORGANIC COMPONENTS
Radicohists, in all the stages of decay. Internal hyphae are rare. **Amorphous material**, very rare, opaque spots, and some smaller red spots. **Spores**, rare, always grouped.

PEDOFEATURES
Sparite is described as coarse material.

Thin section IB138: 20-28.

MICROSTRUCTURE
Some areas of the thin section have moderately developed structure in subangular blocs, accommodated, with interaggregate craze planes and intraaggregate root channels and vughs. Other areas have granular aggregates, but also transitional structures appear. Microstructure is complex, vughy with spongy or granular areas. Some other areas have subangular blocky structure.

GROUNDMASS
Coarse material

quartz, as in IB138: 0-4; **micas,** very rare; **micritic fragments**, similar to IB138: 0-4, but the rounded and desaggregated fragments are more abundant; **sparite**, similar to IB138: 0-4; some crystals are grouped, but their qualification as quemosaics is difficult.

Fine material: Crystallitic b-fabric.

ORGANIC COMPONENTS
Radicohists, less abundant than in IB138: 0-4. Some histons are opaque, looking as ashes; **Amorphous material**, the red one is less abundant than in IB138: 0-4, and the contrary is true for the opaque material; Some **sporangia** appear; hyphae are lacking.

PEDOFEATURES
1.- **Lublinite.** Thin whiskers, some with perpendicular growths. They appear within voids, at times associated to the walls.
2.- **Loose channel infillings,** incomplete, by fecal pellets of 90µmø.

Thin section IB138: 53-58.

MICROSTRUCTURE
Strongly developed pedality in the spongy areas; moderately developed in the other areas. Vughs and some channels, also craze planes appear. Complex microstructure: spongy and some channels and chambers. Also planar microstructure.
GROUNDMASS and ORGANIC COMPONENTS
Similar to the above thin sections (IB138: 0-a, and IB138: 20-28); radicohists are less abundant.

PEDOFEATURES
1.- **Lublinite**. As in the above thin section (IB138: 20-28).
2.- **Loose channel infillings**, more abundant than in IB138: 20-28.

Thin section IB138: 89-97.

MICROSTRUCTURE
Weakly developed microstructure. The outstanding feature are the isles of fine material, surrounded by gypsum. Some isles contain lenticular gypsum. Isles are < 3mm, but a size gradation can be seen, with an important population of isles from 100 to 120μm, until the desaggregated material. Some areas have spongy microstructure. Randomly packed lenticular gypsum appear between the isles; this gypsum is mixed with other individual components of the isles. **Voids** are craze planes as well as channels and chambers. The section has **isles fabric**, with abundance of small (100 to 120μm). Also a structure of fissures and channels appear.

GROUNDMASS
Most groundmass is made by pedofeatures, provided that lenticular gypsum and quesparite are qualified as pedofeatures. The isles' groundmass is similar to the groundmass in the overlying horizons. Spheroidal gravels (1%) show voids and recrystallizations. Groundmass of the isles seems the same, even in the small isles and in those richer in gypsum.

ORGANIC COMPONENTS
These components are similar to the other sections of the pedon, excepted that hyphae and spores do not appear. The organic components occur as well in the fine material isles as in the gypsum lentils mass.

PEDOFEATURES
1.- **Gypsic fabric feature**. This feature is made by a random packing of loose gypsum lentils mixed with other constituents mainly sparite , carbonatic silt and organic components. A gradation to isles appears if these constituents are together. This paragraph describes the components of the gypsic feature fabric that in his turn are considered pedofeatures. Lenticular gypsum with modal size 60μm and maximum size 200μm. Microcrystalline lenticular gypsum (< 1%) in masses of irregular shape (< 300μm), sometimes associated to voids, with crystals are slightly greater than the typical microcrystalline lenticular gypsum and the yellow color in plane light is very faint. Single quesparite crystals (< 1%). Euhedral or subhedral sparite is more scarce than quesparite, and often shows evidences of dissolution. The single silt-sized carbonatic crystals are the finest material, that grade to isles when occur grouped.
2.- **Gypsic features in the isles of fine material**. Intercalary gypsum lentils are very rare in the denser isles, excepted those isles with excremental shape. In the more spongy isles, lenticular gypsum is abundant and could also be considered as belonging to the gypsic fabric feature.
3.- **Coatings.** Gypsum coatings are common in channels and chambers as well as in some planes. This gypsum is lenticular or irregular, and is considered a coating because the ordered disposition related to walls and because the concentration on the walls. Dense clay-silt coatings are associated to root channels. These coatings are sometimes thicker than 100μm, their constituents are not oriented, and their mass is much more dense and red than the mass of the fine material isles. The coatings are often the only or the main feature allowing the identification of a channel in the soil material, because this soil material is quite loose provided is composed by the gypsic fabric pedofeature.
4.- **Infillings.** Fecal pellets (50 to 100μm) produce loose incomplete infillings. In general these pellets do not contain gypsum lentils, but sometimes several pellets coalesce and are mixed with gypsum lentils.
5.- **Pseudomorphic crystals**. Euhedral crystals (< 25μm) within the cells of some root residues, probably whewellite (calcium oxalate) according to their transparency and habit. They are described as pedofeatures because of their euhedral shape, the advanced degree of alteration of the root, and the depth in the soil.

Thin section IB138: 168-182.

MICROSTRUCTURE
Weakly developed pedality. Millimetric isles of fine material. The isles are dense without gypsum, or with more voids and with lenticular gypsum. Some of the isles are quedecal fragments, in all or in part. Granular aggregates from 100 to 200μm are less abundant than in the above thin section (IB138: 89-97). **Voids** are channels and chambers and some horizontal planes. **Isles fabric** with some channels and chambers.

GROUNDMASS and ORGANIC COMPONENTS
As in the above thin section (IB138: 89-97), but with less radicohists.

PEDOFEATURES
1.- **Gypsic fabric feature**. Is similar to the above thin section (IB138: 89-97), but carbonatic silt sized crystals are more abundant. Lenticular gypsum has a modal size smaller than in the above thin section (IB138: 89-97). Microcrystalline lenticular gypsum (2%) is yellower than in the above thin section, moreover this gypsum occurs in regular masses with a regrouping trend that makes composed millimetric nodules containing some lentils and rounded sparite crystals. Carbonatic silt is more abundant than in the above thin section.
2.- **Gypsic features in the fine material isles**. The gypsum coatings of voids are rare. The gypsum infillings of voids are also rare. Some of these infillings are dense, complete, with the gypsum crystals in a radiate disposition. Often it is difficult to decide if these gypsum bodies are infillings or gyprock relics. Intercalar gypsum lentils are rare, and in general appear in quedecal areas.
3.- **Queras.** Residues of queras and deformed queras are 10% of the thin section; complete queras do not occur. Quedecal can make whole isles or be a part of other isles, and uses to contain more lenticular gypsum than the isles parts made by carbonatic fine material. All stages of quemosaics decay can be observed. No cellular envelopes of the quesparite were found in spite of the relative scarcity of single quesparite crystals. *Quefe* (thin iron staining) occur in the cases with a well preserved limit between quedecal and the groundmass.
4.- **Coatings.** Fine carbonatic silt coats some channels and chambers. Lenticular gypsum produces some coats on the carbonatic silt coating. Often the channel or the chamber can be detected only because the coating because the lentils or isles mass is not very dense.

Table 32 Summary field description of pedon IB140

Horizon Depth cm	Color	Structure Friability	Organic matter	Roots	C.fr. = Coarse fragments S.f. = Special features	Boundary
Ap 0-23	10 YR 4/3 moist	Moderate fine subangular blocky - Friable	Few, well in-corporated	Few, very fine and fine vertical, alive.	C.fr.- Few cobbles, subrounded-subspheroidal gypsum with evidences of dissolution	Clear, smooth.
By1 23-70	10 YR 5/3 moist.(7.5 YR 8/2 spots).	Very weak, fine subangular blocky. - Friable.	Very few, well in-corporated	Few, very fine and fine vertical, alive	C.fr.- Frequent, cobbles subrounded-subspheroidal flour-like gypsum. S.f.- Frequent gypsum accumulations (ø < 5 mm).	
By2 70-170↓	10 YR 6/3 moist. (10 YR 8/3 spots).	Fine granular. - Friable.	Very few, well in-corporated	Very few, very fine to coarse, horizontals, alive and death	C.fr.- As in By1, but weathered in surface. S.f.- Very abundant gypsum accumulations (ø < 5 mm).	

Table 33 Analytical characteristics of Pedon IB140

Sample reference and horizon	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25ºC
140/1 Ap	0-23	7.4	2.8	21.4	42.7	2.25
140/2 By1	23-70	7.6	1.8	19.9	49.7	2.25
140/3 By2	90-110	7.8	0.6	5.8	85.7	2.25
140/4 By2	110-140	7.7	0.7	5.8	83.2	2.19
140/5 By2	140-160	7.7	0.7	7.2	79.8	2.19
140/6 -	120-125	7.7	0.7	5.5	-	-

Reference	Particle size distribution				Exchange cations (cmol(+,-) / kg)				
	Sand		Silt 0.05-0.002 mm	Clay <0.002 mm	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC
	2-0.5 mm	0.5-0.05 mm							
140/1	2.27	27.95	59.79	9.99	22.00	0.40	0.15	0.70	23.25
140/2	4.09	26.12	59.02	10.77	22.70	0.70	0.15	0.20	23.25
140/3	0.20	3.94	flocculate	flocculate	10.20	7.30	0.15	0.10	17.75
140/4	-	-	-	-	-	-	-	-	-
140/5	-	-	-	-	5.50	6.40	0.15	0.10	12.15
140/6	-	-	-	-	-	-	-	-	-

Table 34 Summary field description of pedon IB142

Horizon Depth cm	Color	Structure Friability	Organic matter	Roots	C.fr. = Coarse fragments S.f. = Special features	Boundary
Ap 0-25	10 YR 4/3 moist.	Weak, fine subangular blocky. - Friable.	Few, well incorporated.	Few very fine, alive.	C.fr.- Few gravels rounded-tabular, gypsum with dissolution forms, and limestone.	Clear smooth.
By1 25-88	10 YR 4/3 moist. 10 YR 8/3 spots.	Primary strong, fine subangular blocky; secondary by faunal activity.	Very few, well incorporated.	Very few, very fine, alive.	C.fr.- Less that in Ap, only limestone. S.f.- Frequent vermiform gypsum.	Clear, wavy.
By2 88-140l	10 YR 3/3 moist. 10 YR 8/3 spots.	Primary strong, fine subangular blocky; secondary by faunal activity. - Friable.	Very few, well incorporated.	Very few, very fine, alive.	C.fr.- Rare, limestone.	

Table 35 Analytical data of pedon IB142

Sample reference and horizon	Depth cm	pH water 1:2.5	Organic matter (%)	Equivalent calcium carbonate (%)	Equivalent gypsum (%)	EC 1:5 dS/m 25°C
142/1 Ap	0-25	7.6	2.4	33.3	15.0	2.21
142/2 By1	25-88	7.7	3.1	29.1	3.0	2.14
142/3 By2	88-144	7.6	2.2	26.2	8.7	2.23

Reference	Particle size distribution			
	Coarse sand 2-0.5 mm	Fine sand 0.5-0.05 mm	Silt 0.05-0.002 mm	Clay <0.002 mm
142/1	2.06	22.33	63.85	11.76
142/2	1.45	13.05	51.87	33.63
142/3	1.23	12.30	73.52	12.95

Saturated paste											
Reference	Hs (%)	CEe dS/m 25°C	mmol(+,-) / l								SAR
			Ca^{2+}	Mg^{2+}	Na^{+}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}		
142/1	41.0	2.72	29.0	7.0	1.9	lp	3.7	33.0	1.0		0.4
142/2	45.8	2.46	30.0	4.0	lp	ip	2.2	32.0	0.5		0.0
142/3	46.9	2.57	30.0	5.0	0.5	ip	2.0	33.0	0.5		0.1

3.1.3. CLASSIFICATION OF THE SOILS OF IVORRA

Some problems about the denomination and the taxonomical status of gypseous soils were discussed by Herrero and Porta (1991) on the base of Soil Taxonomy System (S.S.S., 1975, 1987). The changes introduced in the sixth edition of Keys to Soil Taxonomy (S.S.S., 1992) did not assume all the proposals made in 1989 by the International Committee on Aridisols I.C.O.M.I.D. (Eswaran and Zi-Tong, 1991). The requirement for a gypsum content in the gypsic horizon higher than that of an underlying horizon (S.S.S., 1975, 1987, 1990, 1992 5th ed.) was dropped out by the new definition of gypsic horizon in the sixth edition (S.S.S., 1992 6th ed.), but the illuviation and secondary gypsum quoted in this new definition are unpractical for soils developed on gyprock or in highly gypseous environments. The subject seems not fully resolved, and an international group of soil scientists (Spaargaren, 1994) postulate the hypergypsic horizon and other changes in the gypseous soils.

Having in mind the above remarks, a tentative classification of the visited soils in the chesa of Ivorra is presented in Table 36. This Table also provides the tentative classification with the last available version of the F.A.O. system (F.A.O., 1990). The low degree of resolution attained could be allowable only if the system was used for small scale maps, according to the initial purpose of this system. The different definition of gypsic horizon by F.A.O. (1990) and by S.S.S. (1992 6th ed) is a big problem when both systems are used concurrently.

Table 36. Classification of Ivorra soils after S.S.S. (1992 6th ed., and denomination according to F.A.O. (1988).

Pedon	Soil Taxonomy (S.S.S., 1992 6th ed.)	F.A.O., 1990
IB 153	-	-
IB 136	Typic Xerorthent, loamy, gypsic, mesic, shallow.	Lithic Leptosol
IB 151	Typic Calcixeroll, coarse silty, gypsic, mesic.	Gypsic Kastanozem
IB 134	Gypsic Xerochrept, coarse loamy, gypsic, mesic.	Haplic Gypsisol
IB 135	Gypsic Xerochrept, coarse silty, gypsic, mesic.	Calcic Gypsisol
IB 138	Gypsic Xerochrept, fine silty, carbonatic, mesic.	Haplic Gypsisol
IB 142	Gypsic Xerochrept, fine silty, mixed, mesic	Haplic Gypsisol

The underlying rock in pedon 136 is a gyprock. It is assumed to be a hardrock in spite of its low hardness (2 on Mohs' scale), because it does not allow root penetration, therefore its classification as Lithic Leptosol.

Pedon IB134 shows a very common taxonomical problem in soils developed on gypseous materials due to the unfeasability, even using micromoprphology, of distinguish and quantify the gypsum from pedological origin. Moreover the environmental or behavioural differences between all kinds of gypsum are irrelevant, as was stressed by Tavernier et al. (1981), ICOMID (1989), Herrero (1991), Herrero et al. (1992), and others. The pedon IB134, qualifies as gypsic if the genetic considerations in the S.S.S. (1994) definition of this diagnostic horizon are not taken in account.

The epipedon of IB151 qualifies as mollic because of the waiver for colour value established in Soil Taxonomy (S.S.S., 1992 6th ed., page 5) for high calcium carbonate equivalent contents. This waiver might be enlarged to gypsum because it has a similar action as white pigment. In this pedon, the particle-size class has to be established from the feel determination of texture, because the current laboratory methods for granulometry are unsound with this amounts of gypsum. Feel texture is always subjective, and in the flour-like gypsum highly influenced by the water content, but the estimation of clay by the formula proposed by S.S.S. (1992 6th ed., page 29) is arguable because of the limited information about the physical behaviour of this soils materials with 95% gypsum. Similar consideration that IB134 can be done about gypsic horizon, because the genesis of the flour-like gypsum is not yet well established. Another possible discussion is if the gypsic characteristics of this soil are well represented at the family level, or if a Gypsic subgroup might be established within the Calcixerolls.

The classification of IB135 do not show the presence of a calcic horizon, in spite of the calcic horizon overlies the gypsic. In this case the system of F.A.O. (1990) reflects better this fact.

An important difference between profile IB138 and IB142 is the higher gypsum content (> 50%) of IB138 in its gypsic horizon, against <10% gypsum in the gypsic horizon of IB142. The physical properties of the soil are conditioned by this difference, that can not be reflected at the family level. The different vertical distribution of gypsum content in these soils cannot either be reflected in their denominations, in spite of the genetical and functional meaning.

3.2. SOILS ON ALLUVIAL-FANS FROM TERTIARY GYPSUM OUTCROPS

Only one profile has been selected from the Algerri site to be shown in the excursion. This is due to the fact that some profiles of this sector show morphologies not present in other sites already visited during the excursion.

3.2.1. SOIL-LANDSCAPE RELATIONSHIPS

Several small ephemeral water courses and one permanent river coming from the so-called pre-pyrenean ranges (Montsec) cross the Barbastro-Balaguer anticline and build up several alluvial fans. Those alluvial fans have different age and reach different heights above the level of the present-day drainage system. The lower ones merge to the contact depression behind the higher encrusted terraces of the Segre and Noguera Ribagorçana rivers, which is a very common feature of the Ebro Valley. The following discussion is restricted to the west of Farfanya river. Full information is available from Olarieta et al. (1991) and Margarit et al. (1995).

The remnants of the old alluvial fans contain very often a large quantity of limestone gravels. Lower levels have much less coarse materials. Accumulation of calcium carbonate and gypsum is a common feature, leading to the formation of soils with both calcic and gypsic horizons. This fact is again more prominent in the coarse materials which show nodules, pendents and in the case of the calcium carbonate indurated accumulations.

The finer materials in valley bottoms usually contain small quantities (<15%) of vermiform gypsum, in some cases linked to salt-affected soils. Nevertheless, some points of the present valley bottoms are occupied by soils with more than 50% of gypsum throughout, similar to the El Castell del Remei site. These facts are more prominent near the contact depression.

A noticeable feature of these soils is the high calcium carbonate content. Several soil series belong to carbonatic families. It should also be mentioned the removal of calcium carbonate from the top horizon which is clearly noticeable macromorphologically and chemically. This removal is always partial, because the $CaCO_3$ content of these topsoils is never found below 15%.

Also in the gravelly alluvial fans gypsum is almost absent in the top horizons, but reaches considerable amounts (50% and more in some cases) in the lower ones.

The chosen site to be visited has the characteristic of showing induration of the gypsic horizon. Although other soils of the area have also these morphologies to some degree, this cannot be considered a very common feature of the area.

3.2.2. SOIL CHARACTERISTICS AND PROPERTIES

The representative profile corresponds to a Gypsic Xerochrept. Its description (macro and micromorphological) and physico-chemical properties are found in Table 37.

Table 37 Macromorphological and analytical characteristics of "Algerri" (Margarit *et al*, 1995).

Location Algerri
UTM x 30250
y 463050
Elevation 300 m a.s.l.
Ref. Map: IGN Sc. 1:50 000, Sheet

Parent material
Detrital terrigenousmaterials containing gypsum

Soil temperature regime: mesic

Soil moisture regime:
xeric (Newhall 1976, mod. Jarauta 1989) or aridic

Geomorphology
Slope. Scale: several hm. Profile situated on a flat area, modified by levelling. Local slope: 2 - 5%

Hydrology
Soil drainage class: well drained

Vegetation
Rainfed agriculture, cereals

Human influences
Extensive traditional agriculture
Chemical fertilizers and liquid pig manure are currently applied

Stoniness absent
Bedrock outcrops absent
Salinity and alkalinity no evidences
Cracking absent
Compaction absent

Classification: Gypsic Xerochrept, fine-silty, carbonatic, mesic.(SSS 1992 6th ed.)
Petric Gypsisol (FAO 1990)

PROFILE DESCRIPTION (SINEDARES): (colours for moist soil)

A p 0 - 34 cm
Slightly moist; oxidized; brown (7.5 YR 4/6); without mottles; loam; few coarse fragments; weak very coarse subangular blocky structure; somewhat compact, friable; abundant, few organic matter; normal roots; reaction to HCl 11% very strong; no cracks; without accumulations; abrupt (due to plough pan) and smooth boundary. OCHRIC.

B w k 34 - 96 cm
Slightly moist; oxidized; brownish yellow (10 YR 6/6); without mottles; loam; frequent coarse fragments; weak coarse subangular blocky structure; somewhat compact, friable; normal roots; reaction to HCl 11% very strong; few $CaCO_3$ accumulations as pendents and coatings on coarse fragments; abrupt and smooth boundary. CALCIC.

2B y m 96-130 cm
Slightly moist; oxidized; brownish yellow (10 YR 7/6); without mottles; abundant coarse fragments; slightly cemented by gypsum; rooting system affected by cementation; reaction to HCl 11% very strong; generalized accumulations of gypsum as crystals and vermiform gypsum. PETROGYPSIC.

ANALYTICAL DATA. PROFILE "ALGERRI"

Horizon	Depth (cm)	pH (H_2O) 1:2.5	OC (%)	EC 25°C 1:5 (dS/m)	Textural class
Ap	0-34	8.42	0.78	0.27	L
Bwk	34-96	8.40		0.26	L
2Bym	96-130	8.04		2.08	

Particle size distribution USDA				Available P (ppm)	Available K (ppm)	$CaCO_3$ (%)	Gypsum (%)
Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)				
2.38	36.81	39.72	21.09	9.07	121	25.95	< 1
4.12	36.93	39.33	19.62			39.25	2.3
						15.94	59.18

Micromorphological descriptions

Common features: Organic components absent, speckled brownish-yellow micromass, mixture of clay, fine silt and microsparite. Crystallitic b-fabric.

Structure and porosity	c/f	Coarse mineral components	Pedofeatures
Bym 110-120 cm			
Pedal, very weakly developed, subangular blocky, very coarse sand size. Isles fabric locally. 50% pores: vughs, packing pores, biopores, planar voids in gypsum mass, vertically oriented.	Limit: 15 µm relation: 1:1 porphyric to enaulic	intercalary gypsum crystals, medium sand; limestone fragments, very coarse sand; few mica flakes, quartz and feldpars.	Few decarbonated areas of micromass, irregular. Nodules and pore coatings of idio- to hypidiotopic gypsum crystals, fine to coarse sand size. Masses of xenotopic gypsum crystals (50% of the groundmass), vertical layered structure, highly porous, probably due to dissolution. Typic impregnation nodules of iron oxi-hydroxides.
Bym 125-130 cm			
Apedal. Vughy to single grain structure. Some areas of isles fabric. 50% pores: vughs, packing pores, biopores and planar voids.	Limit: 15 µm relation: 2:1 close porphyric to enaulic	Mainly gypsum crystals, hypidio- to xenotopic, sand size, very poorly sorted. Fragments of gyprock, coarse sand size.	Gypsum pendents, without orientation. Coatings of xenotopic gypsum crystals. Few decarbonated areas.
Bym 150-160 cm			
70% porosity. Horizontally laminated mass of hypidio- to xenotopic gypsum crystals in palisade, perpendicularly oriented to the surface. Layers of 1 to 2 mm thick , with inner ondulating layers of micrite. All the horizon is in dissolution. The micrite layers act as the squeletton of the horizon.			

Bym 120-160 cm			
Angular blocky structure, aggregates 3 mm ø. 60 % porosity: packing pores, vughs and planar voids in gypsum mass of crystals.	Limit: 15 μm relation: 3:1 enaulic	Gravels of biogenic limestone, subplanar, horizontally oriented, weakly sorted, in bands. Gypsum sand-size crystals, idio- to hypidiotopic, very poorly sorted.	Nodules of microcrystalline gypsum. Nodules of xenotopic gypsum, partly merged to the groundmass. Dense coatings of gypsum in palisade around coarse fragments, some of them with dissolution features. Banded distribution of the micromass, in layers of 2 cm thick, showing isles fabric. $CaCO_3$ - depletion nodules, medium sand size in the micromass, randomly distributed.

3.2.3. SOIL GENESIS AND PRESENT DYNAMICS

Gypsiferous soils are found at the footslopes of an anticline, on colluvial materials, hence the origin of gypsum may be partly colluvial, though some fractions may have been transported by dissolution through subsurface flow. The presence of layered gypsum observed in some soils could be related to this subsurface flow along the slopes, in a process similar to the one described by Wieder & Lavee (1990), or to mud flows from the anticline (Herrero et al., 1992). The processes leading to the bedded deposits in sebkhas and saline pools are not likely to occur, since the geomorphological characteristics of the area (reduced source area, formation of the soils on colluvium) do not allow it.

Notwithstanding the possible lateral origin of gypsum in some soils through surface or subsurface flow, there are also clear evidences of downward accumulation of gypsum, which causes the typical vertical zonation calcic-gypsic in some of the soils. The presence of gypsum pendents and coatings on coarse fragments may be related to the same phenomenon. These type of soils are absent in the Urgell, although it could be considered that in the Urgell an horizontal zonation occurs (hypergypsic horizons are laterally associated to petrocalcic ones, at the edge of the Ondara alluvial fan), related to the lateral origin of gypsum.

The induration -cementation- of the gypsic horizon observed in the profile is not a present-day process, as it is evidenced by the micromorphological features of horizon Bym. The layered orientation of micritic material within the cemented gypsic horizons suggests that the process of induration may have taken place during or just after the formation of the sediment, before some hydrological changes in the drainage regime took place, as a lowering of the base level. These changes could be the beginning of the process of dissolution of the cemented horizons, still in progress.

3.2.4. SOIL CLASSIFICATION

The problems in the classification of this soil arise mostly from the soil moisture regime requirements. Xerochrepts do not have a subgroup for soils with a petrogypsic horizon. Also the field identification of this horizon is far from clear in both taxonomies (FAO 1990 and Soil Taxonomy, SSS 1992, 6th ed.).

3.3. SOILS ON QUATERNARY ALLUVIAL DEPOSITS (URGELL SITE)

3.3.1. SOIL - LANDSCAPE RELATIONSHIPS

An overview of the distribution of the mapping units comprising gypsiferous soils in the Urgell shows that the largest spot of soils with hypergypsic horizons (ICOMID, 1989; Eswaran & Zi-Tong, 1991) is located at the edge of the Ondara-alluvial fan. Other highly gypsiferous soils are found in elongated patches, associated to distal parts of the Corb river drainage network. Soils with minor amounts of gypsum are either distributed around the previous ones, they follow drainage network patterns or constitute soil associations with Fluvents.

3.3.2. MORPHOLOGY OF GYPSUM ACCUMULATIONS

Vermiform gypsum, nodules and coatings
Vermiform gypsum appears as fine undulating tubes (< 5 mm long, 1 mm in diameter) with a soft consistency in the field. In thin sections vermiform gypsum corresponds to infillings or coatings of lenticular gypsum in biopores. Accumulations of vermiform gypsum are ubiquitous in all the studied gypsiferous horizons. They occur in gypsic and hypergypsic horizons, in calcareous, calcareous-gypsiferous or even gypsiferous matrices, where the vermiform gypsum is recognized by a lower chroma and a higher value.

Coarse crystallizations
Coarse crystals appear in gypsic horizons, where they have been described as **individual crystals** from coarse sand size to 15 mm in diameter (size increasing with depth), lenticular or razor blade or **desert-rose types**, from 5 mm to very coarse crystals (> 10 cm). Crystals are sometimes twinned and contain poikilotopic inclusions of micrite. Desert roses and individual crystals have been found together with celestite newformations and with redox pedofeatures. Some karst features appear at the surface of the fields.

Powdery gypsum (horizons of lenticular gypsum)
Powdery gypsum is only found in soils with hypergypsic horizons, with gypsum contents from 60 to 80%. These materials are normally characterized in the field by a matrix with a 10 YR 4-6/2-3 moist colour, showing abundant vermiform gypsum accumulations and characterized by a rough and powdery feeling. In thin section the groundmass consists of gypsum lenses of medium or coarse sand size (coarse elements) scattered in a micritic (calcareous) micromass. Faunal activity is very high. Isles fabric is another feature associated with these materials, often as localized spots in the thin sections. Roots are seldom, and when present, they develop along faces of vertical fissures. Karstification phenomena are very frequent.

Horizons of microcrystalline gypsum (flour-like horizons)
The horizons with microcrystalline gypsum correspond to hypergypsic horizons with very high gypsum content, ranging between 86 and 90%. They have colours with very high hues (10 YR 6-7/3-2). These horizons look very homogeneous materials, dull yellow orange, friable and with a flour-like feeling. Roots do not penetrate these horizons except through vertical cracks or pre-existing faunal channels. The boundaries with the under and overlying horizons are often abrupt. They consist of a mixture of lenticular and microcrystalline gypsum (sizes between 20 and 100 µm), with small quantities of scattered micrite. These

horizons show, as in the case of powdery gypsum, some features related to faunal activity and dissolution and collapse phenomena due to gypsum karsts.

Bedded gypsum layers
Bedded gypsum layers are the deepest gypsiferous materials found in those profiles, overlying coarser materials (gravels or sands). They consist of an alternation of layers of gypsum and a yellowish brown mud (clay loam). They also appear in some hypergypsic horizons as alternating horizontal layers with different gypsum content.

Other crystalline pedofeatures
Cystalline pedofeatures other than gypsum consist of celestite crystals and of several features related to calcite accumulation. **Celestite** is found as fine needles, up to 200 μm in length and 30 μm thick, grouped in nests of sand size, or scattered in the groundmass. No relation has been found between the distribution of celestite and other features, though it shows a tendency to crystallize in biopores. The pedofeatures related to **calcite** accumulation are mainly nodules, calcite pseudomorphs after lenticular gypsum, and pendents under coarse fragments. They are not very frequent, which stresses the little importance of calcite redistribution in these soils.

The relation between the different types of gypsum accumulation and their position in the landscape is displayed in Fig. 14, which shows a soil transect across the main physiographic units of the Pla d'Urgell.

3.3.3. SOIL CHARACTERISTICS AND PROPERTIES

In the excursion three profiles will be visited: a soil with a hypergypsic horizon and two soils with gypsic horizons.

3.3.3.1. SOILS WITH HYPERGYPSIC HORIZONS

The soils having a hypergypsic horizon (ICOMID, 1989; Eswaran & Zi-Tong, 1991) are located at the margins of the Ondara Platform or are found in the central plain of the Urgell, under the influence of the Corb alluvial fan. All these soils have a limited use for agriculture, due basically to the shallowness of gypsum-rich materials and to the karstification of the underlying horizons.

In most of them gypsum content is lower at the surface (between 50 and 60%) and increases reaching about 90% in the hypergypsic horizons. The underlying materials consist either of gravels or alternating layers of gypsum and silt over gypsum free coarser materials.The types of gypsum accumulations are powdery gypsum, microcrystalline gypsum, bedded gypsum layers and vermiform gypsum. Many of them are strongly affected by gypsum karsts.

The selected profile (Castell del Remei) is located at the margin of the Ondara alluvial fan. The macro, micromorphological and analytical data are found in Table 38.

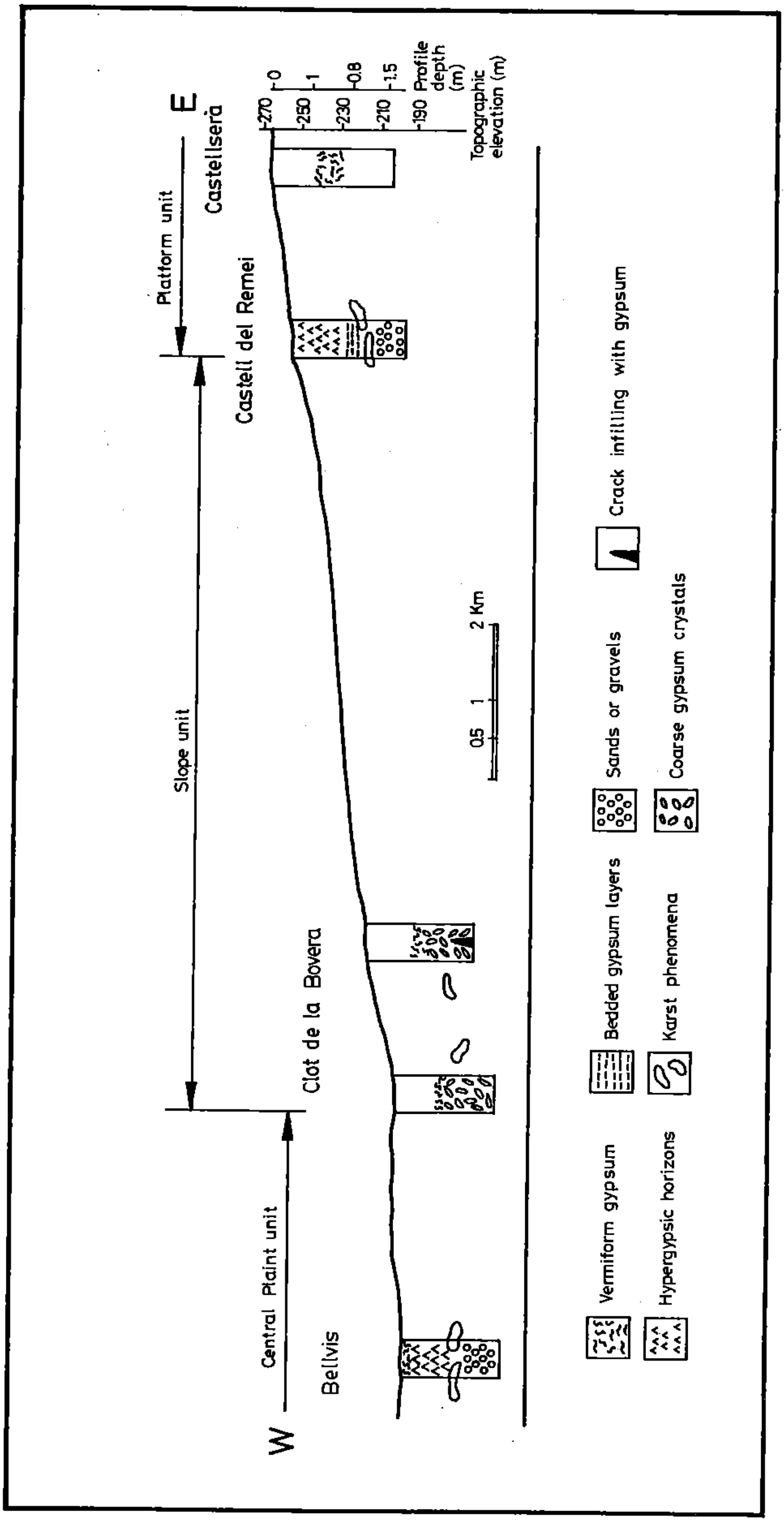


Figure 14. Position of the visited profiles along a transect and their relation with the main physiographic units in El Pla d'Urgell

Table 38 Macromorphological description of the soil "Castell del Remei" (Poch, 1992)

Location: El Pla d'Urgell, La Fuliola
UTM x 33220
y 461995
Elevation: 255 m (± 5) asl
Ref. Map: IGN Sc. 1:25 000, Sheet 360-IV

Parent material:
Gypsum-rich, silty alluvial materials.

Substratum
Quaternary alluvial deposit of alternating gypsum and calcareous muddy layers between 80 and 110 cm. Incoherent sandstone below.

Soil temperature regime: mesic

Soil moisture regime:
xeric (Newhall 1976, mod. Jarauta 1989)

Geomorphology
Regional landform: Alluvial fan of the Ondara river, which flows from E to W and disappears in the Pla d'Urgell itself. Scale: several km Profile located on a distal position (last km). Local landform: Flat bottom Scale: several dam, Profile located on a flat area. Local slope: < 1%

Hydrology
Water table at 110 cm. Abandoned field surrounded by irrigated fields with drainage by open channels. The water level is higher in summer (period of irrigation) and lower in winter. Soil is affected by karstification due to gypsum dissolution, evidenced by the presence of sinkholes at the surface
Runoff class: medium
Hydraulic conductivity: Moderate to moderately rapid
Internal soil drainage: Medium
Soil drainage class: Moderately well drained

Vegetation
Sparse shrub vegetation.Species present: Cynodon dactylon, Gypsophyla tomentosa, Brachypodium sp.

Human influences
The field is abandoned at present, although it was used for agriculture some years ago. It is periodically burnt to eliminate the spontaneous vegetation.

Stoniness absent
Bedrock outcrops absent

Salinity and alkalinity
whitish salt efflorescence at the surface

Organic matter
fragments of charcoal

Microrelief
partly undulating, due to karstification

Cracking absent
Compaction absent

Classification: **Gypsic Xerochrept, coarse-silty, gypsic, mesic (SSS 1992 6th ed).**
Haplic Gypsisol (FAO 1990)

PROFILE DESCRIPTION (CATSIS)

A y 0-23 cm
Moist; oxidized; brown (10 YR 5/3) when moist and pale brown (10 YR 6/3) when dry; without mottles; silt loam; without coarse fragments; moderate fine subangular blocky; not very compact, no sticky, very plastic, firm; non cemented; moderate (2-5%) organic matter, humus; normal rooting system, abundant very fine to coarse roots, randomly oriented, regularly distributed, live; reaction to HCl 11% very strong; few accumulations of vermiform gypsum, fine, soft and discontinuous; clear smooth boundary. OCHRIC, HYPERGYPSIC

B y1 23-23/37 cm
Moist; oxidized; dark greyish brown (10 YR 4/2) when moist, light grey (10 YR 7/2) when dry; without mottles; silty clay loam; without coarse fragments; moderate coarse subangular blocky; compact, no sticky, very plastic, friable; non cemented; few infilled worm casts; frequent very fine roots, randomly oriented, regularly distributed, live; reaction to HCl 11% very strong; frequent accumulations of vermiform gypsum, fine, soft and discontinuous; clear broken boundary (discontinuous horizon, developed in pockets). HYPERGYPSIC.

B y2 23-23/65 cm
Moist; oxidized; greyish brown (2.5 Y 5/2) when moist, white (2.5 Y 8/2) when dry; without mottles; silt loam; without coarse fragments; weak coarse subangular blocky; not very compact, no sticky, very plastic, firm; non cemented; frequent very fine to coarse roots, live, randomly oriented, regularly distributed and also associated to cracks (closed at the moment of the description); reaction to HCl 11% very strong; frequent accumulations of soft fine vermiform gypsum, increasing with depth; gradual broken boundary (discontinuous horizon). HYPERGYPSIC

Y 23-65/76 cm
Moist; oxidized; pale brown (10 YR 6/3) when moist, white (2.5 Y 8/2) when dry; without mottles; silt; without coarse fragments; massive; not very compact, no sticky, plastic, very friable; non cemented; few faunal cavities; abundant very fine to coarse living roots, randomly oriented, regularly distributed and also associated with cracks (closed at the moment of the description); reaction to HCl 11% strong; abundant accumulations of soft fine vermiform gypsum; abrupt wavy boundary. HYPERGYPSIC

2C y 65/76-95 cm
Wet; oxidized; dark yellowish brown (10 YR 4/4) when moist, pale brown (10 YR 6/3) when dry, with light yellowish brown (2.5 Y 6/4) when moist, white (2,5 Y 8/2) when dry layers 2 cm thick in 1/3 of the horizon; very few and very fine clear and distinct mottles, associated to roots, brownish yellow (10 YR 6/6) moist; silty clay loam; without coarse fragments; apedal; not very compact, slightly sticky, very plastic; non cemented; very few and very fine to coarse roots; reaction to HCl 11% very strong; few accumulations of vermiform gypsum; abrupt smooth boundary. GYPSIC.

3C 95-110 cm
Saturated; oxidized; light grey (2.5 Y 7/2) when moist, white (2.5 Y 8/2) when dry; without mottles; silt; without coarse fragments; apedal; not very compact, no sticky, very plastic; non cemented; few prominent small spots of humic material, abrupt and irregular, distributed in layers; silt; reaction to HCl 11% very strong; abrupt smooth boundary.

4C g > 110 cm
Saturated; oxidized; yellowish brown (10 YR 5/4) when moist, light yellowish brown (10 YR 6/4) when dry; frequent clear distinct mottles, medium and irregular; few and small prominent spots of humic material, abrupt boundary, irregular shape, distributed in layers; fine sandy loam; without coarse fragments; apedal; no sticky, very plastic; non cemented; incoherent sandstone; reaction to HCl 11% very strong; without accumulations.

ANALYTICAL DATA. PROFILE: "CASTELL DEL REMEI"

Horizon	Depth (cm)	Colour Munsell (moist)	pH (H_2O) 1:2.5	E.C. 1:5 dS/m 25°C	OC (%)	Textural class
Ay	0-23	10YR 5/3	8.1	2.92	1.20	L
By1	23-23/37	10YR 4/2	8.3	3.03	0.98	CL
By2	23-23/65	2.5Y 5/2	8.1	2.30	0.43	SCL
Y	23-65/76	10YR 6/3	8.0	2.12		SL
2Cy	65/76-95	10YR 4/4	7.9	1.75		CSi
3C	95-110	2.5Y 7/2	8.0	0.92		CL
4Cg	>110	10YR 5/4	7.9	0.84		SL

Particle size distribution USDA Method: Vieillefon (1977)			Moisture content (%)		Available water (%)	$CaCO_3$ (%) Method: TG	Gypsum (%) Method: TG
Sand (%)	Silt (%)	Clay (%)	-33 kPa	-1500 kPa			
50.0	35.2	14.8	23.1	15.8	7.3	13	59.6
42.4	29.9	27.7	25.6	20.6	5.0	14	64.5
54.1	17.7	28.2	23.8	14.0	9.8	12	77.7
62.7	22.2	15.1	13.5	2.8	10.7	6	87.9
9.3	45.2	45.4				27	9.5
37.1	35.5	27.4				48	0.8
65.6	23.1	11.3				17	1.0

Cations extracted by NH_4OAc 1N pH 8.2 (cmol(+)/kg)				CEC (cmol/kg)	V (%)	EC 1:1 dS/m 25°C
Na^+	K^+	Ca^{2+}	Mg^{2+}			
2.5	0.3	269.8	13.1	6.2	100	6.5
2.1	0.3	269.8	14.0	7.2	100	7.2
0.4	0.0	539.2	3.6	4.0	100	3.4
0.3	0.0	292.5	1.7	2.0	100	2.8
0.5	0.2	140.3	4.7	13.2	100	3.0
0.2	0.1	26.5	1.6	2.5	100	2.8
0.2	0.1	31.8	1.9	5.4	100	2.8

Soluble salts (mmol(+-)/l) extract 1:1							
Na^+	K^+	Ca^{2+}	Mg^{2+}	Sr^{2+}	SO_4^{2-}	Cl^-	HCO_3^-
19.5	1.87	23.9	41.5	0.31	67.9	9.2	2.8
19.8	1.40	23.5	39.7	0.35	57.2	5.2	2.5
6.2	0.18	31.5	8.5	0.34	44.0	1.0	2.0
3.9	0.12	33.4	7.1	0.39	40.6	0.9	1.4
5.3	0.20	33.6	9.3	0.31	46.2	1.2	2.5
2.8	0.26	32.6	6.5	0.50	36.9	0.8	1.1
2.2	0.34	45.5	5.9	0.36	53.2	0.5	0.8

MICROMORPHOLOGICAL DESCRIPTIONS

Structure and porosity	c/f	Coarse mineral components	Micromass	Organic components	Pedofeatures
Ay 0-10 cm Lenticular Hypergypsic, sandy loam, calcareous.					
Moderate coarse subangular blocky. Intra-aggregate vughy and channel microstructure. Pores 35 %: Channels and chambers, planar voids, vughs.	c/f limit 10 μm c/f ratio 35/30 Enaulic to close porphyric	Lenticular gypsum crystals, fine sand, 30%. Limestone fragments with pseudomorphs of micritic calcite after lenticular gypsum, 5%.	Yellowish brown speckled micromass : calcite and silt. Crystallitic b-fabric.	Root sections up to 4 mm diameter and few excrements. Charcoal fragments and plant residues.	Patches of isles fabric. Isles of calcitic micromass from 500 to 3000 μm diameter, some with a layered internal fabric. Bow-like distributions of gypsum crystals. Aggregate nodules and coatings on pores of hypidiotopic gypsum crystals. Amiboidal nodules of microcrystalline gypsum.
By1 19-34 cm Lenticular Hypergypsic, sandy loam, calcareous.					
Fissure and intra-aggregate channel microstructure. Pores 20 %: Planar voids, channels and chambers	c/f limit 10μmc/f ratio 40/40Single to double spaced porphyric	Lenticular gypsum crystals, fine sand size, 40%. Few subangular equant quartz grains, medium sand size.	Yellowish grey speckled micromass: fine silt, clay and micritic calcite. Crystallitic b-fabric.	Root remains in channels.	Bow-like distributions of gypsum crystals. Loose continuous and discontinuous infillings of gypsum crystals. Loose continuous infillings of microcrystalline gypsum.Pore coatings of micritic calcite. Loose discontinuous infillings of micritic calcite in pores. Typic nodules of micritic calcite. Angular fragments of clay and micritic calcite with a parallel internal layering.
By2 22- 40 cm Lenticular Hypergypsic, sandy loam, calcareous.					
Coarse subangular blocky, channel intrapedal. Pores 40%:Planar voids, channels and packing pores	c/f limit at 10 μm c/f ratio 40/20 Enaulic to close porphyric	Gypsum crystals, few equant quartz grains, few limestone fragments.	Greyish-brown speckled micromass: clay and micritic calcite, crystallitic b-fabric.	Id. before.	Loose channel infillings of gypsum. Nodules and coatings of hypidiotopic gypsum crystals around some pores. Bow like arrangements of lenticular gypsum. Anisotropic distribution of loose gypsum lenses in pores, closer to the lower side, sometimes in palisade. Pseudomorph of calcite after a lenticular gypsum crystal. Typic nodules of micrite.
Y 50 cm Lenticular Hypergypsic, sandy loam, calcareous.					
Vughy microstructure. Pores 40 %: Vughs, simple packing pores, channels.	c/f limit at 15 μm. c/f ratio 37/3. Enaulic to close porphyric	Lenticular gypsum crystals. Few hornblende grains and limestone fragments.	Id. before.	Id. before.	Loose discontinuous infillings of pure lenticular gypsum in pores. Parallel orientation patterns of gypsum referred to some voids. Bow-like arrangements of gypsum. Typic nodules of microcrystalline gypsum, medium sand size. Pseudomorph of calcite after gypsum.

2Cy 70-80 cm. Horizon made up of two kind of materials, distributed in parallel oriented layers. The layers of material I (non gypsic) have a width of 100 μm to 1.5 cm. Layers of material II (gypsic) have a width between 0.5 and 1 cm.					
Material I Lenticular Eogypsic, silt loam, calcareous					
Channel microstructure. Pores 20 %: channels and chambers.	c/f limit at 15 μm c/f ratio 30/50 Open porphyric	Quartz grains, calcite crystals and calcareous sandstone fragments.	Yellowish-brown speckled micromass: calcite, fine silt and clay, with greyish brown layers parallel to the soil surface. Crystallitic b-fabric.	Nodules of amorphous organic matter, root and cell and excrements in channels. Banded distribution or organic components.	Typic micrite nodules, calcite pseudomorphs after lenticular gypsum. Micrite accumulations and coatings. Few gypsum crystals. Bow-like arrangements of gypsum. Infillings of gypsum in pores. Lines of Fe-oxides, 20 μm thick, up to 4 mm long, broken by lenticular gypsum crystals. Pyrite framboids, partly weathered, of fine sand size, in the zones with more organic matter.
Material II Lenticular (locally petric) Hologypsic, fine sand					
Intergrain microaggregate Pores 40 %: Complex and simple packing pores, vughs and channels.	c/f limit at 20 μm, c/f ratio 50/10. Enaulic	Lenticular gypsum crystals from 20 to 900 μm, poorly sorted, (mode 200 μm)	Greyish brown speckled micromass, made of calcite, silt and some clay. Crystallitic b-fabric	Root remains.	Bow-like and concentric arrangements of lenticular gypsum. Gypsum coatings around vughs and channels. Typic nodules of microcrystalline gypsum, coarse sand size.
2Cy 85-95 cm Horizon made of two different materials. The upper part is the same as material I (non gypsic) described in the previous section. A Gasteropod fossil of 2 mm in diameter is observed in this material. Microcrystalline Hologypsic, silt					
Apedal material with a massive microstructure Pores 30 %: Simple packing pores, vughs and channels.	c/f limit 10 μm c/f ratio 60/10 Close porphyric.	Lenticular gypsum crystals, poorly sorted, ranging from 20 to 700 μm.	Microcrystalline gypsum. Gypsic microcrystalline b-fabric.	Absent.	Intercalations, pore coatings and infillings of calcitic micromass. Aggregate nodules and coatings of hypidiotopic gypsum. Typic nodules of microcrystalline gypsum.
4Cg 110 - 130 cm					
Apedal material, complex channel and fissure microstructure. Pores 25 %: Channels, planar voids and vughs.	c/f limit at 10 μm, c/f ratio 40/35, single spaced porphyric	Quartz, microcline and plagioclase grains and calcite crystals, limestone fragments	Yellowish grey speckled micromass, with brown yellowish speckled bands, mixture of calcite, clay and fine silt. Crystallitic b-fabric.	Few root sections of 50 μm diameter.	Typic micritic calcite nodules, impregnative nodules of amorphous organic matter, moderately impregnated, amiboidal; pseudomorphs of micritic calcite after root sections. Impregnative nodules of iron oxy-hydroxides.

3.3.3.2. SOILS WITH GYPSIC HORIZONS

The soils with a gypsic horizon have a broad range of properties. The gypsum content in these soils is often nihil at the surface and increases in depth, sometimes in a sudden way, which is a reflection of levelling works or of buried horizons by new alluvial sediments. In some of the cases the substrate has not been reached, and therefore it has been assumed that the gypsic horizon stops somewhere in depth, because of the alluvial nature of the parent material.

Gypsum is found as vermiform accumulations, nodules, coatings, pendents or as coarse crystallizations. Carbonate accumulations are not observed. Two profiles have been selected: "Castellserà" and "Clot de la Bovera". The descriptions of these soils (field and micromorphological) and their physico-chemical characteristics are found in Tables 39 and 40 respectively.

Both soils are developed on fine calcareous alluvial materials with vermiform gypsum below 50 cm (up to 30% of gypsum at the bottom of the soil). They are deep soils, differring in drainage class: "Castellserà" is well drained while "Clot de la Bovera" is moderately well drained and shows evidences of gypsum dissolution and collapse of surface materials in the field.

Table 39 Macromorphological and analytical characteristics of "Castellserà" (Herrero *et al*, 1993).

Location El Pla d'Urgell, Penelles
UTM x 32860
y 462033
Elevation 236 m (±5m) asl
Ref. Map: IGN Sc. 1:25 000, Sheet 360-III

Parent material
Fine detrital terrigenous materials

Soil temperature regime: mesic

Soil moisture regime:
xeric (Newhall 1976, mod. Jarauta 1989)

Geomorphology
Bottom. Scale: several hm. Profile situated on a flat area, modified by levelling. Local slope: < 2%

Hydrology
The soil is subjected to flooding irrigation from the Canal d'Urgell, with drainage by open channels.

Soil drainage class: well drained

Vegetation
Natural vegetation eliminated, due to agricultural landuse. Crop: onions.

Human influences
Extensive traditional agriculture. Chemical fertilizers and liquid pig manure are currently applied.

Stoniness	absent
Bedrock outcrops	absent
Salinity and alkalinity	no evidences
Cracking	absent
Compaction	absent

Classification: Gypsic Xerochrept, fine-silty, mixed, mesic.(SSS, 1992 6th ed.)
Haplic Gypsisol (FAO 1990)

PROFILE DESCRIPTION (SINEDARES): (colours for moist soil)

A p 0 - 30 cm
Moist; oxidized; brown (10 YR 4/5); without mottles; silty clay loam; without coarse fragments; compound granular structure; somewhat compact, friable; abundant, few organic matter; human activity: rests of stubble; normal roots; no cracks; no accumulations; abrupt (due to plough pan) and smooth boundary. OCHRIC.

B w 30 - 45 cm
Moist; oxidized; brown (10 YR 4/5); without mottles; silty clay loam; without coarse fragments; massive; very compact, extremely firm; roots affected by the compacity of the horitzon; without accumulations; clear and smooth boundary.

B wy1 45 - 75 cm
Moist; oxidized; brown (7.5 YR 4.5/6); without mottles; silty clay loam; without coarse fragments; primary structure: strong subangular blocky, secondary structure: prismatic; compact, firm; rooting system normal; without cracks; clay coating; frequent vermiform gypsum accumulations; clear and smooth boundary.

B wy2 75 - 120 cm
Slightly moist; oxidized; brown (10 YR 4/5); without mottles; loam; without coarse fragments; strong subangular blocky; compact, friable; frequent vermiform gypsum accumulations; clear and smooth boundary. GYPSIC.

ANALYTICAL DATA. MODEL PROFILE "CASTELLSERÀ" (Herrero *et al*, 1993)

Horizon	Depth (cm)	pH (H_2O) 1:2.5	OC (%)	Textural class
Ap	0-30	8.1-8.7	0.5-1.75	SCL
Bw-Bwy1	30-60	8.2-8.8		SCL
Bwy1-Bwy2	60-120	8.2-8.8		SCL/L

Particle size distribution USDA			Available water (%)	$CaCO_3$ (%)	Gypsum (%) Method: TG
Sand (%)	Silt (%)	Clay (%)			
0-37	45-75	18-25		17-27	<2
0-30	45-65	25-40	15-18	17-29	1-5
0-30	45-65	25-40	15-18	17-29	5-10

Cations extracted by NH_4OAc 1N pH 8.2 (cmol(+)/kg)				CEC (cmol/kg)	Sodicity (SAR)	V (%)	EC 1:1 dS/m 25°C
Na^+	K^+	Ca^{2+}	Mg^{2+}				
				8-10	5-10	100	2-4
				8-10	5-10	100	4-8
				8-10	5-10	100	4-8

Table 40 Macromorphological description of the soil "Clot de la Bovera" (Poch, 1992)

Location El Pla d'Urgell, Bellvís
UTM x 32244
y 461840
Elevation: 210 m (± 5m) asl
Ref. Map: IGN Sc. 1:25 000, Sheet 360-III

Parent material
Fine alluvial calcareous deposits with gypsum crystals, and possible earthwork material at the surface.

Substratum id.

Soil temperature regime: mesic

Soil moisture regime:
xeric (Newhall 1976, mod. Jarauta 1989)

Geomorphology
Regional landform: alluvial fan of the Ondara river, which flows from E to W and disappears in the Pla d'Urgell itself. Scale: several km, Profile located on a distal position (last km). Local landform: Flat bottomed area, levelled. Scale: several hm. Local slope: < 1%.

Hydrology
The soil is subjected to flooding irrigation from the Canal d'Urgell, with drainage by open channels. The water table is lower in winter and reaches its highest level during summer (period of irrigation). Few sinkholes ("coladors") are observed in the field, although there is no evidence of gypsum dissolution in the profile.
Runoff class: 3 (medium)
Hydraulic conductivity: Moderately slow
Internal soil drainage: Di3 (medium)
Soil drainage class: D3 (moderately well drained)

Vegetation
Natural vegetation eliminated, due to agricultural landuse.

Human influences
The soil has possibly been levelled for irrigation purposes.

Stoniness	absent
Bedrock outcrops	absent
Salinity and alkalinity	without evidences
Organic matter	corn stubble buried by ploughing
Microrelief	none
Cracking	absent
Compaction	absent

Classification: **Gypsic Xerochrept, fine, mixed, mesic**
Haplic Gypsisol (FAO 1990)

PROFILE DESCRIPTION (CATSIS)

A p 0 - 20 cm
Slightly moist; oxidized; brown (7.5 YR 4/3); without mottles; silty clay loam; frequent fragments of calcareous siltstone, 0.2-6 cm in diameter, subrounded-tabular, randomly oriented, regularly distributed, coated with carbonates; primary structure: strong medium subangular blocky; secondary structure: moderate medium crumb; no coherent, friable; biological activity: frequent faunal channels and chambers; organic matter: few, well incorporated; reaction of the matrix to HCl 11% very strong; without accumulations; abrupt (due to ploughing) and smooth boundary. OCHRIC.

B w 20 - 50 cm
Slightly moist; oxidized; brown (7.5 YR 4/3); without mottles; silty clay loam; few fragments of calcareous siltstones; 0.2-6 cm in diameter, subrounded-tabular, randomly oriented, regularly distributed, coated with carbonates; moderate coarse subangular blocky, fine juxtaposed structure due to faunal activity, < 25% in volume; compact and firm; biological activity: frequent faunal channels and chambers, some of them infilled; human activity: plough pan; rooting system limited by the compacity of the horizon, very few, fine and very fine roots, randomly oriented, along ped faces, dead by end of agricultural cycle; reaction of the matrix to HCl 11% very strong; without accumulations; clear and wavy boundary.

B w y 50 - 90 cm
Slightly moist; oxidized; brown (7.5 YR 4/4); without mottles; silt loam; very few fragments of calcareous siltstones, 0.2-6 cm in diameter, subrounded-tabular, randomly oriented, regularly distributed, coated with carbonates; moderate medium subangular blocky; compact and friable; biological activity: frequent faunal channels, some of them infilled, and few worm channels; rooting

system limited by the compacity of the horizon, very few, fine and very fine roots, randomly oriented, along ped faces, dead by end of agricultural cycle; reaction of the matrix to HCl 11% very strong; accumulations: (1) frequent fine vermiform gypsum, in root channels and pores, soft and discontinuous, (2) few gypsum crystals, sand size; clear and wavy boundary. GYPSIC.

2B y1 90 - 125 cm
Moist; oxidized; dark brown (10 YR 3/3); without mottles; silty clay loam; without coarse fragments; primary structure: weak medium subangular blocky; secondary structure: moderate medium crumb; compact and very friable; abundant, well incorporated organic matter; biological activity: few faunal infilled channels; without roots; reaction of the matrix to HCl 11% very strong; accumulations: (1) frequent vermiform gypsum, fine, in pores, soft and discontinuous, orange (7.5 YR 6/8); (2) frequent vermiform gypsum, fine, in pores, soft and discontinuous, light brownish grey (7.5 YR 7/2); (3) frequent lenticular gypsum crystals, sand size, throughout all the horizon, in voids as nests; diffuse and smooth boundary. GYPSIC.

2B y2 125 - 155 cm
Wet; oxidized; brown (10 YR 4/6); scarce faint clear mottles, < 2 mm in diameter, irregular, due to reduction, with no relation to other characters; silty clay loam; without coarse fragments; compact; very weak coarse subangular blocky; reaction of the matrix to HCl 11% very strong; accumulations: (1) frequent gypsum crystals, fine (< 5 mm), (2) frequent desert roses of gypsum, fine; gradual and smooth boundary. GYPSIC.

2C y > 155 cm
Saturated; oxidized; yellowish brown (10 YR 5/6); scarce faint clear mottles, < 2 mm in diameter, irregular, due to reduction, with no relation to other characters; sandy loam; without coarse fragments; sand mineralogy: lenticular gypsum crystals; massive; compact; reaction of the matrix to HCl 11% very strong; accumulations of lenticular gypsum, powdery, as coatings and infillings of cracks, < 5 mm thick, vertical, slightly hard, continuous. GYPSIC.

ANALYTICAL DATA. PROFILE "CLOT DE LA BOVERA"

Horizon	Depth (cm)	Colour Munsell (moist)	pH (H_2O) 1:2.5	E.C. 1:5 dS/m 25°C	OC (%)	Textural class
Ap	0-20	7.5YR 4/3	8.7	0.24	2.02	SiCL
Bw	20-50	7.5YR 4/3	8.4	1.40	1.21	SiCL
Bwy	50-90	7.5YR 4/4	8.5	2.19	0.56	SiC
2By1	90-125	10YR 3/3	8.5	2.07	0.34	CL
2By2	125-155	10YR 4/6	8.5	1.97	0.29	CL
2Cy	>155	10YR 5/6	8.6	1.75	0.12	L

Particle size distribution USDA Method: Vieillefon (1977)			Moisture content (%)		Available water (%)	$CaCO_3$ (%) Method: TG	Gypsum (%) Method: TG
Sand (%)	Silt (%)	Clay (%)	-33 kPa	-1500 kPa			
12.7	50.2	37.2				29	0.0
4.6	56.9	38.5				30	3.1
11.5	45.0	43.5	24.0	18.6	5.3	27	17.5
30.4	31.5	38.1	20.5	16.5	4.0	16	31.9
34.1	30.8	35.2	14.7	11.6	3.1	20	38.6
38.0	37.0	25.0				20	48.1

Cations extracted by NH_4OAc 1N pH 8.2 (cmol(+)/kg)				CEC (cmol/kg)	V (%)	EC 1:1 dS/m 25°C
Na^+	K^+	Ca^{2+}	Mg^{2+}			
0.3	0.4	34.3	5.3	11.2	100	0.9
0.4	0.3	58.4	5.8	21.5	100	2.9
0.5	0.3	150.7	6.5	14.9	100	3.1
0.5	0.3	186.2	7.7	14.9	100	3.3
0.4	0.2	184.8	4.7	8.8	100	3.2
0.3	0.1	223.9	4.4	6.3	100	3.3

Soluble salts (mmol(+-)/l) extract 1:1							
Na^+	K^+	Ca^{2+}	Mg^{2+}	Sr^{2+}	SO_4^{2-}	Cl^-	HCO_3^-
1.4	0.34	7.9	2.6	0.07	9.5	0.7	5.4
4.0	0.11	45.8	12.3	0.31	52.0	0.4	2.7
5.0	0.11	31.4	14.0	0.26	55.1	0.8	1.4
4.6	0.09	32.6	11.8	0.28	51.7	0.9	1.3
3.8	0.13	31.4	11.2	0.29	47.5	0.7	0.8
3.3	0.15	33.6	14.0	0.27	62.3	0.6	0.7

MICROMORPHOLOGICAL DESCRIPTIONS Profile "Clot de la Bovera"

Structure and porosity	c/f	Coarse mineral components	Micromass	Pedofeatures
Bw 25-40 cm Lenticular Gypsic, silt loam, calcareous. Hydromorphic syndrome.				
Apedal, vughy. Pores 20%: vughs and channels	limit 15 μm, ratio 1/3, double spaced porphyric	medium and coarse sand, quartz, feldspars and limestone. Shell and bone fragments	yellowish brown speckled mixture of clay and micrite. crystallitic b-fabric.	Very few aggregate nodules of Fe-oxihydroxides, medium sand size. Some loose infillings of gypsum in biopores.
Bwy 50-60 cm Lenticular Gypsic, silt loam, calcareous. Hydromorphic syndrome.				
apedal, channel. Pores 20%: channels, few cracks and vughs	id.	quartz grains mostly	id., with undulating bands of components with different sorting	Loose infillings and coatings of lenticular gypsum, frequent contact twins; few gypsum lenses in the groundmass, sometimes following bow-like arrangements and/or mixed with organic material; orthic nodules of Fe-oxihydroxides, moderately to strongly impregnating, irregular, dendritic, coarse sand size; celestite nests, medium sand size.
Bwy-2By1 85-100 cm Lenticular Gypsic, silt loam, calcareous. Hydromorphic syndrome. Id. as before, but larger gypsum crystals, often twinned (swallow-tail), and some celestite nests. Isles fabric.				
2By1 100-125 cm Petric (locally lenticular) Gypsic, silt loam, calcareous. Hydromorphic syndrome. id. as previous one, except for more frequent and larger gypsum crystals, and very frequent celestite nests. The gypsum infillings contain some micromass, their c/f related distribution being chitonic to enaulic. Clay-rich zones, in bands or interlacings are also observed.				
2By2 130-140 cm Petric (locally lenticular) Gypsic, silt loam, calcareous. Hydromorphic syndrome. id. as before, with more frequent gypsum, larger crystals. Celestite needles also scattered in the groundmass				
2Cy >155 cm Petric (locally lenticular) Gypsic, silt loam, calcareous, hydromorphic syndrome; with coatings 0.5 cm thick of petric hologypsic. id. before, with few irregular spots of decarbonated micromass, and vertical cracks (1 cm thick) which are dense complete infillings of hipidio to xenotopic gypsum crystals, medium to coarse sand size.				

3.3.4. SOIL GENESIS AND PRESENT DYNAMICS

The genesis of the gypsiferous soils from the Urgell are associated to alluvial-fan deposits. These formations are coarse-textured, extremely permeable, and they allow much of the discharge to happen through subsurface runoff. Gypsum was probably brought in solution by the rivers to the Urgell, circulating through the coarse-textured materials of their alluvial fans before precipitation above or close to them, in a similar way described by Neal (1972) and Krinsley (1970) in playa-margin environments. In these places massive gypsum deposits are more likely to develop, as it has been discussed: both powdery and microcrystalline gypsum horizons may form in these conditions provided that a gypsum-saturated water from a shallow water table is supplied.

The presence of bedded gypsum deposits underlying some of those hypergypsic materials as it happens in the profile Castell del Remei, where also biogenic sulphur has been identified, indicates that the water level was at least for some time over the soil surface. This situation is to be expected in a marshy environment with an irregular surface and where a changing groundwater level would intercept periodically the soil surface in the depressions. Moreover, the micromorphological study has revealed the existence of fragments of such crusts in surface powdery gypsum horizons, associated to a high faunal activity. This indicates that, at least in some soils, the powdery gypsum horizon is derived from a gypsum bedded material undergoing a severe bioturbation.

Coarse crystallizations appear mostly in fine-textured materials, either along river valley bottoms associated with Fluvents or underlying hypergypsic horizons. Their genesis is closely influenced by the watertable fluctuation, as discussed by several researchers over the "croûtes de nappe" (Pouget, 1968; Tolchel'nikov, 1962). The grading of the gypsum crystals in the soil "Clot de la Bovera" with increasing sizes from top to bottom (where the water table is more permanent) also supports this hypothesis. The fluctuation of the water table in the past is evidenced by the presence of gypsum infillings of fissures at the bottom of the soils, where swelling-shrinking clays are present: the fissures would develop during drier periods, and gypsum would precipitate there from a deeper water table.

With respect to the soils with vermiform gypsum accumulations but without hypergypsic horizons, the origin of gypsum could be a subsurface water flow from the Corb and Ondara rivers, but also the hypergypsic horizons themselves could have acted as a gypsum source after a change of the hydric conditions of the Urgell. They would be the origin of "second generation" gypsum, accumulated in soils downstream (a process also described through aeolian transport by Watson (1985) in gypsum crusts from Tunis), or exporting the gypsum in solution to the Segre river. The most striking evidence of this change is the generalized development of gypsum karsts at the base of hypergypsic horizons.

Human influence plays also a role in the soils of the Urgell, brought about by the change in landuse from rainfed to irrigated, that took place 100 years ago. Indeed, the high quality of the irrigation water and the change of the drainage network have surely contributed to dissolve part of the gypsum from these source areas and to distribute it to other parts of the Urgell that were not attained by the former natural drainage network. The magnitude of gypsum dissolution in the region was studied by Navas (1990, 1991), who stresses the importance of gypsum income from the non-point sources to the Ebro river and its tributaries: 45% of the total gypsum in the river is brought by the 6% of water coming from non-point sources (other than rivers). The mean gypsum concentration of the Segre reaches 139 mg/l when it runs along the Urgell, while at the Segre headwaters (100 km upstream) the concentration is 26 mg gypsum/l (period 1970-85; Navas, 1991). The runoff water from the gypsiferous anticline is surely partly responsible for this fact, but since the Urgell is the largest irrigated area along that river reach its contributions to the increase of dissolved gypsum in the river must be significant as well.

Besides the change in landuse, the irrigation practices may also play a role in the present dynamics of gypsum and salts in the soils. In reality it is a common practice in the area to use drainage water to irrigate the fields because irrigation and drainage channels are often interconnected. Boixadera et al. (1989b) estimated the amount of gypsum that would accumulate in the soil if it was irrigated with 500 mm of water from different known sources in the Urgell. Considering no leaching losses, the values are 8610 kg/ha for water from a drainage ditch, 1341 kg/ha for water from a well and 77 kg/ha for water from the main irrigation channel. If we take this amount in a yearly basis, the time necessary to accumulate 5% of gypsum in 15 cm of soil (minimum requirement for a gypsic horizon; SSS, 1985) is 10, 67 and 1170 years of continuous irrigation respectively.

These indicative figures suggest that, although it is impossible to distinguish the natural from the man-induced gypsum accumulations, the continued irrigation practices during 100 years must have had a significant influence on the formation of some gypsiferous soils in the region. The presence of brik and pottery fragments below horizons with gypsum accumulations in some soils also supports this statement.

Regarding soil use, hypergypsic horizons in this area present a limited use for agriculture or for grazing, due to the difficulties for the development of roots and to the generalized collapse of the upper horizons. Soils with gypsic horizons that have been visited also have a limited use for agriculture, due to gypsum contents above 30% at shallow depths and to imperfect drainage, which impedes the growth of deep-rooting crops.They are moderately suitable for irrigation, as artificial drainage is needed to maintain a low water table, and also due to the process of karstification itself.

3.4. SOIL CLASSIFICATION

The classification of gypsum-rich soils under xeric moisture regime has undergone numerous modifications since its first edition (SSS, 1975, 1985, 1987, 1990,1992 5th ed, 1992 6th ed.), and their adequacy to gypsiferous soils from Spain has been thoroughly discussed elsewhere (Porta & Herrero, 1990; Herrero, 1991). Following these successive classification proposals, the same soil having a gypsic horizon or other gypsum redistributions has received different names (Table 41), depending on the depth at which this horizon starts and on other diagnostic characteristics, like a fluventic character.

Table 41 Examples of classification of gypsiferous soils under Xeric moisture regime, accordin to successive editions of Soil Taxonomy (SSS, 1975) and Keys to Soil Taxonomy (SSS 1985, 1987, 1990, 1992 1992 5th ed, 1992 6th ed.)

SSS	Soil with gypsic horizon within 1 m	Soil with gypsic horizon, upper limit within 1 m (*)	Soil without gypsic horizon, with gypsum
1975	Gypsiorthid	Gypsiorthid	Torriorthent
1985	Typic Xerochrept Fluventic Xerochrept	Torriorthent	Torriorthent
1987	Gypsic Xerochrept	Torriorthent	Torriorthent
1990	Gypsic Xerochrept	Xerorthent Xerofluvent	Xerorthent Xerofluvent
1992 5th ed	Gypsic Xerochrept	Typic Xerochrept	Xerorthent Xerofluvent
1992 6th ed	Gypsic Xerochrept	Typic Xerochrept	Xerorthent Xerofluvent

(*) The fraction above 1 m not fulfilling the requirements for gypsic

Furthermore new proposals for gypsum-rich diagnostic horizons are still under discussion. With the original proposal of the hypergypsic horizon (ICOMID, 1989; Eswaran & Zi-Tong, 1991), 3 diagnostic horizons with gypsum accumulations would exist.

The presence of the hypergypsic under xeric moisture regime bordering aridic is explicitely recognized by the ICOMID (1989), therefore it would have to be included in the lower levels of the other soil orders. Assuming that this horizon has the same diagnostic importance as the gypsic in the region, a new subgroup might be added to the Xerochrepts, namely the Hypergypsic Xerochrept (Eswaran, 1989 pers. com.), which should key out before the Gypsic Xerochrept.

It should be noted that the hypergypsic horizon has not been included in the last versions of the Keys to Soil Taxonomy (SSS 1992 5th ed, 6th ed). Instead, in the new definition of the petrogypsic horizon it is indicated that this horizon is "cemented or indurated" to the extent that roots cannot penetrate except along vertical fractures. In this way the new petrogypsics has been broadened to include part of the hypergypsics when they do not allow root penetration.

The depth requirements for the diagnostic horizons in Aridisols and in Inceptisols are not the same. For example, a soil having a gypsic horizon with its upper boundary within 100 cm from the soil surface, but whose fraction within these 100 cm by itself does not fulfill the requirements for the gypsic horizon, would be classified as a Gypsid under an aridic moisture regime (SSS 1992 6th ed.) but might be a

Typic Xerochrept under a xeric one in absence of other diagnostic horizons. It means that the same "gypsic" character is expressed at the suborder level in the aridisols whilst it could not be integrated at least in the suborder level in other orders.

The criterium of the upper boundary within 1 m is justified in the aridisols because of the subsidence problems that may appear when the soils are irrigated, even when the gypsic is very deep (SSS 1975, ICOMID 1989). With the inclusion of the hypergypsic horizon, and under a xeric moisture regime, this criterium is indeed more strengthened, hence it seems reasonable to apply at least the same depth requirements for gypsic and hypergypsic under xeric moisture regime. In the cases where a calcic horizon overlies the gypsic, a Calcigypsid group is proposed (SSS 1992 6th ed.). If the same criterion is followed under a xeric moisture regime, both horizons would have to be reflected at the subgroup level, as Calcic Gypsic Xerochrepts. With the present classification these soils are Calcixerollic Xerochrepts.

Another point of discussion is related to the alluvial nature of the parent material, causing the fluventic character in many of the soils. Unfortunately the last editions of "Keys to Soil Taxonomy" (SSS 1990, 1992 5th ed, 1992 6th ed.) exclude the possibility of combining qualifiers in the subgroups, unless in some specific cases, since the definitions are written in a "key" way up to that level. The presence of calcium carbonate accumulation or of aquic diagnostic characteristics can neither be reflected at this level.

In spite of that, it is necessary to express this information in the soil name at the subgroup level, as well for soil survey and mapping purposes (Gypsic Xerochrepts in the region often form soil associations with Typic Xerofluvents (Boixadera et al, 1989; Herrero et al 1993) as for expressing "marks or causes of sets of processes that appear to dominate the course or degree of soil development, ... or to modify the marks of other processes" , as it was originally stated about the subgroup classifiers in Soil Taxonomy (SSS 1975).

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