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3.3. Irrigation from the Sixties: Flumen-Monegros

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3.3. Irrigation from the sixties: Flumen-Monegros

3.3.1. Introduction

In arid and semiarid areas, agricultural land use is mainly restricted, in the first place, by the availability of water for crop growth.

The transformation to irrigation of about 600 000 ha in the Ebro Valley has led to high increases in yield and in diversity of crops.

After the Spanish Civil War (1936-39), which was followed by II World War, the Spanish food production system was heavily disrupted and food shortages appeared. This put high pressure on the development of new irrigated schemes which had been planned many years ago.

In the Flumen-Monegros area, the technology available in the late fifties was based on flood-irrigation systems, with no previous soil studies, an empirical land evaluation, no control of saltinization risk and, finally, levelling without topsoil preservation.

The extension of salinity and/or sodicity-affected soils in the Ebro Valley (IRYDA, 1977) was 200 000 ha, from which 160 000 were located in Aragon, mainly in Bardenas, Cinca and Flumen-Monegros area. But Alberto et al. (1984) reckron this data in 300 000 ha. As a result of these studies, ILACO (1975) designed two experimental drainage plots.

Although the existence of salt-affected soils was known, information about the extent, location and general functioning at landscape level of those soils was lacking in the area. Some of the problems related to land use and soil management which are present now in the area or can be expected in the near future are:

- Salinity-Sodicity: Diagnosis, monitoring and rehabilitation of salt-affected soils.
- Soil structural degradation and surface crust formation.
- Need for improved efficiency in water use: irrigation technology, water reuse,...
- Control of drainage-system degradation: open-air drains as well as underground drains.

Several approaches at different scales have been adopted to work on these issues. Satellite images have been used to monitor land use and its temporal variability. Classical soil mapping at 1:100000 level have been performed; in addition various detailed studies have been undertaken in model areas using the electromagnetic and four electrode sensors, micromorphological techniques, scanning electronic microscopy, and land evaluation procedures.

The results have been presented in several papers: about salinity-sodicity trends in the Flumen sector (Herrero, 1987); about parameters related to water behaviour (Aragües, 1986); about soil porosity in plough horizons (Rodríguez-Ochoa, 1998); about translocation of solid materials (Rodríguez-Ochoa, et al. 1989; Porta and Rodríguez-Ochoa, 1991; Rodríguez-Ochoa, 1998); about degradation of underground drainage systems by mineral siltation (Herrero et al. 1989; Rodríguez-Ochoa, et al. 1989; Muñoz, 1991; Rodríguez-Ochoa, 1998).

Other studies performed in the area include: Soil-vegetation relationships (Herrero, 1981); laboratory trials with different amendments in the drainage trench infilling material (Porta et al. 1996); dispersive processes because of soil structural instability (Amézketa and Aragüés, 1990; Aragüés and Amézketa, 1991; Amézketa and Aragüés, 1995) and degradation of the hydraulic conductivity of soils (Amézketa and Aragüés, 1989; Aragüés and Amézketa, 1991; Amézketa and Aragüés, 1995).

The trip to the Flumen-Monegros area undertakes some of these points, and the stops are located in some of the main soil units.

Discussion will be centered on aspects of soil genesis, classification and mapping, land use and soil conservation.

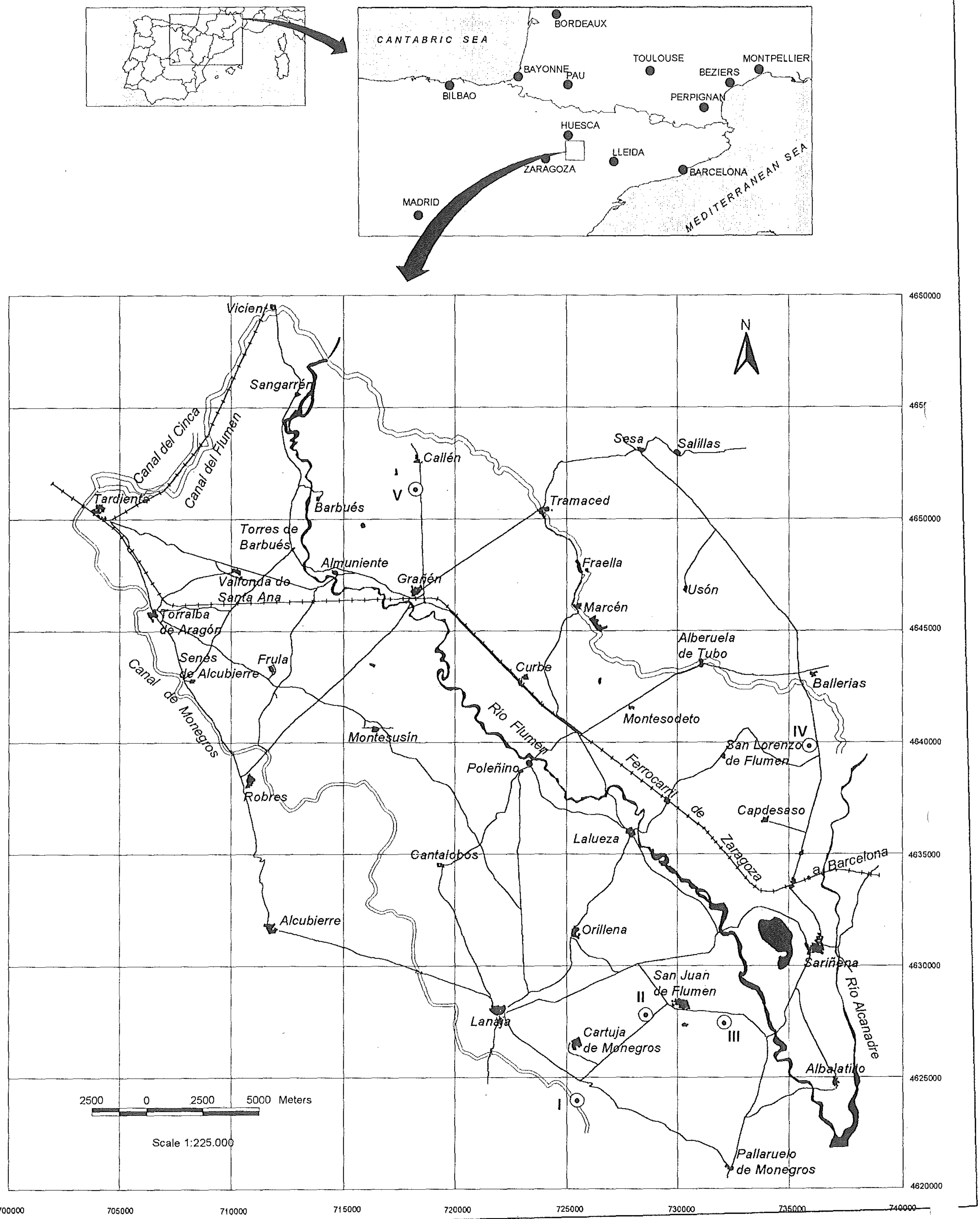


Figure 3.3. 1. Location of the study area. Itinerary of the excursion: Stops I,II,III, IV and V.

3.3.2. Description of the area

3.3.2.1 Climate

The mountains around the Ebro Depression condition the climatic characteristics in the area. Mean annual rainfall is low (300-600 mm) and with a large annual and interannual irregularity. Mean annual temperature is around 14-15 °C; during the winter fog is frequent and during the summer the mean temperature is 24°C and the maximum temperature reaches 43°C. Dominant winds in the area are of NW direction (cierzo) which is cold, dry and blasted; or SE (bochorno) which comes from Mediterranean and is hotter and wetter.

Climatic characteristics of the area have been obtained from the Sariñena station of the INM (National Meteorologic Institute); its location and data series are shown on Table 3.3.1.

Table 3.3. 1. Observatory location.

Observatory	Latitude	Longitude	Altitude (m)	Data series	
				Temperature	Rainfall
Sariñena	41° 47´30´´N	0° 09´20´´ W	281	1969-1989	1945-1989

As shown on Table 3.3.2, July is the hottest month, with the lowest rainfall.

Table 3.3. 2. Mean monthly air temperatures and rainfall in Sariñena.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DEC	ANNUAL
Mmt	5.0	7.2	10.2	13.1	17.5	21.7	29.3	24.2	20.4	15.3	8.7	5.1	14.5
Mimt	0.9	2.1	4.4	7.0	11.0	15.0	18.1	17.6	14.1	9.9	4.1	1.3	8.8
Mamt	9.1	12.3	16.0	19.2	24.0	28.5	32.5	30.9	26.7	20.6	13.4	8.9	20.2
MimT	-1.5	-1.7	1.9	5.0	9.2	13.2	15.8	15.1	10.9	5.7	1.2	-1.6	7.7
MamT	11.6	16.8	20.5	22.2	28.2	32.2	34.1	33.3	29.8	22.7	16.3	11.6	21.7
Rain	30.0	26.5	32.9	32.8	46.0	44.4	26.5	28.7	39.5	38.9	30.2	32.7	408.6

Mmt: Means of the mean monthly air temperature
Mimt: Means of the mean minimum monthly air temperature
Mamt: Means of the mean maximum monthly air temperature
MimT: Means of the absolute-minimum monthly air temperature
MamT: Means of the absolute-maximum monthly air temperature

The ombrothermic diagram (Figure 3.3.2) shows that the dry period extends from June to September.

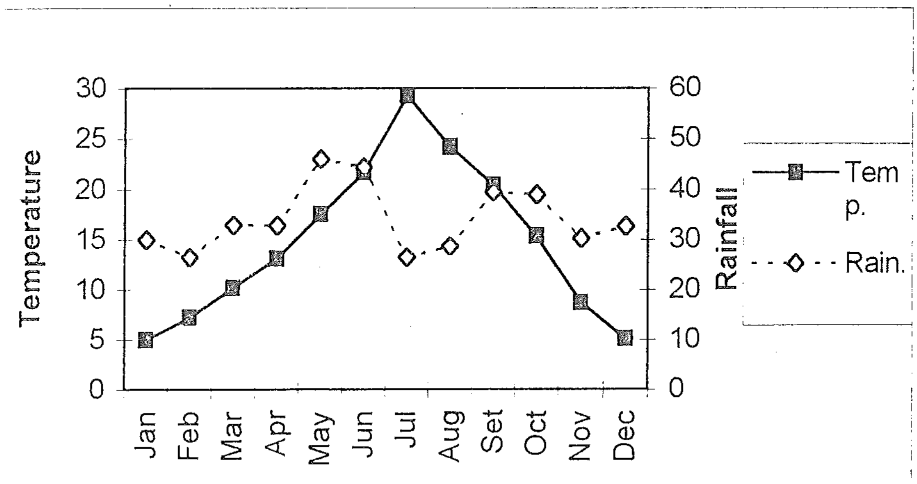


Figure 3.3. 2. Ombrothermic diagram (Sariñena).

The water balance has been estimated considering Thornthwaite´s potential evapotranspiration (PET, Table 3.3.3.) or the reference crop evapotranspiration using the Blaney-Criddle (modified by FAO,1977) equation (ET_0, Table 3.3.4), and using a value of 100 mm for the available soil water holding capacity -ASWHC- in both cases

Table 3.3. 3. Water balance, PET calculated by Thornwaite. Data in mm.

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	30	26.5	32.9	32.8	46	44.4	26.5	28.7	39.5	38.9	30.2	32.7
PET	7.8	14.4	35.6	59.4	101.4	146	183.6	162.8	114.1	61.2	22.4	9.2
R-PET	22.2	12.1	-2.7	-26.6	-55.4	-101.6	-157.1	-134.1	-74.6	-22.3	7.8	23.5
CPL		-41.7	-44.4	-71	-126.4	-228	-385.1	-519.2	-593.8	-616.1		
SM	53.5	65.8	64.1	49.2	28.2	10.3	2.1	0	0	0	7.8	31.3
Deficit	0	0	1.0	11.6	34.4	83.7	148.9	131.9	74.6	22.3	0	0

CPL: Cumulative potential losses
SM: Soil moisture

Table 3.3. 4. Water balance, ET_0 calculated by Blaney-Criddley. Data in mm.

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	30	26.5	32.9	32.8	46	44.4	26.5	28.7	39.5	38.9	30.2	32.7
ET_0	12.4	36.4	74.4	102	151.9	198.4	225	204.6	138	74.4	30	15.5
R- ET_0	17.6	-9.9	-41.5	-69.2	-105.9	-154	-198.5	-175.9	-98.5	-35.5	0.2	17.2
CPL	-105	-114.9	-156.4	-225.6	-331.5	-485.5	-684	-859.9	-958.4	-993.9	-	-
SM	35	31.7	21.01	10.47	3.6	0.7	0	0	0	0	0.2	17.4
Deficit	0	6.6	30.81	58.66	99.03	151.1	197.8	175.9	98.5	35.5	0	0

CPL: Cumulative potential losses
SM: Soil moisture

The actual water deficit extends at least from March to October, and the soil profile cannot be recharged by rainfall during the wet period. The dry period coincides with the plant growing season and crop production under rainfed conditions is not cost-effective many years. Irrigation increases crop profits and leads to crop diversification.
Using Soil Taxonomy (1975) the soil temperature regime is thermic for all the Monegros-Flumen area.
The Jarauta Model (1989) has been used to define the soil moisture regime considering four values of available soil water holding capacity –ASWHC- (50, 75, 100 and 200 mm) and 4 crop coefficients (Rodríguez-Ochoa, 1998). The results show that the area is in the boundary between aridic and xeric regime according to Boixadera (1989) in Garrigas (Lerida), we consider xeric regime when ASWHC is larger than 70 mm and aridic otherwise.

3.3.2.2. Geology

After the Alpine orogeny, marine regression during the late Eocen period led to continental sedimentary conditions. During the Mio-Pliocene period a strong change occurs in these sedimentary conditions. After the Ebro river opened an outlet to the Mediterranean sea, through the Costera Catalana Mountains, the sedimentary regime was modified and during the Quaternary period an alternance in erosive and sedimentary phases took place.

In some areas Tertiary materials outcrop, but most of the surface is made from Quaternary materials. A map of geological materials in the area is shown on Figure 3.3.3.

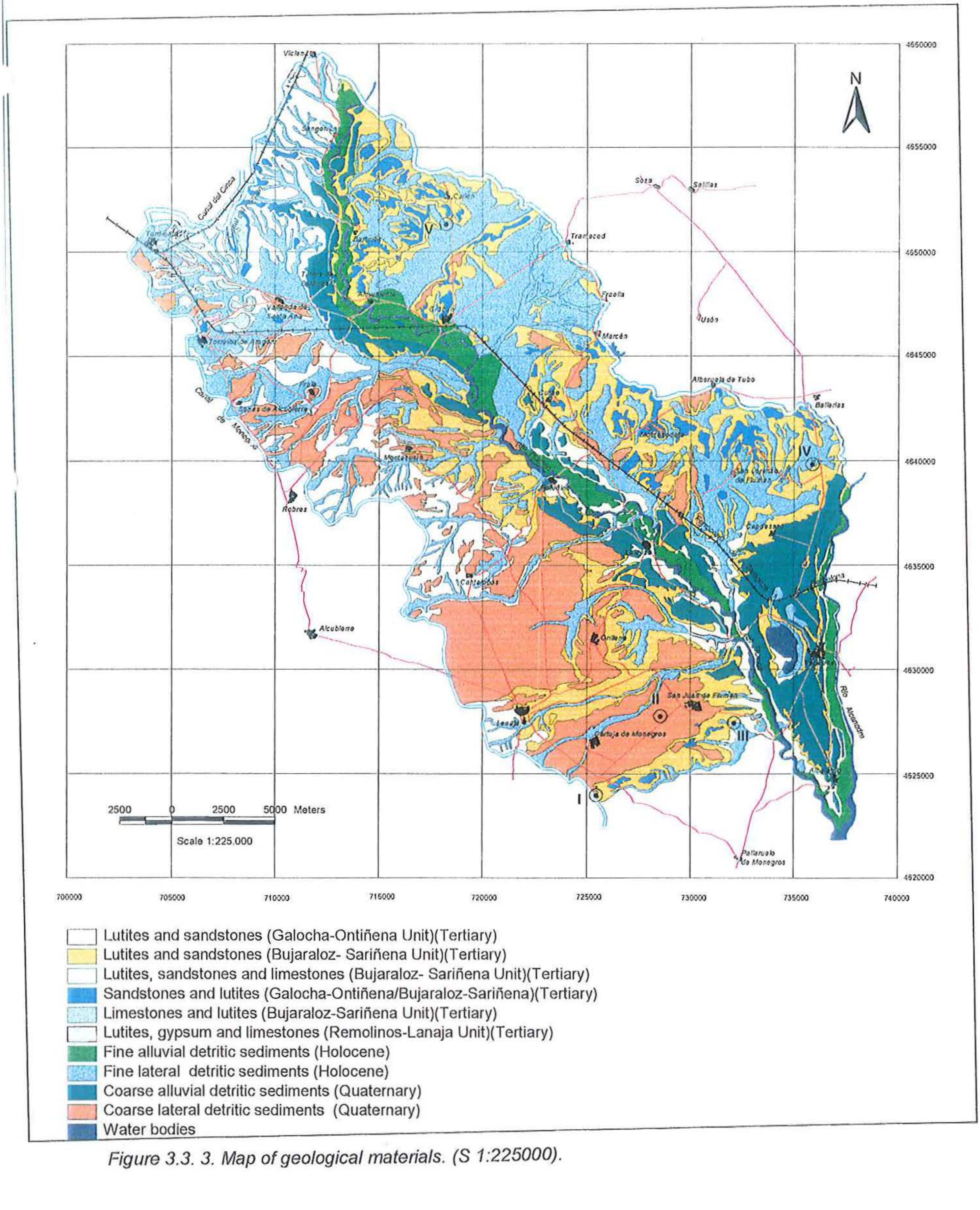


Figure 3.3. 3. Map of geological materials. (S 1:225000).

3.3.2.2.1. Tertiary Units

- **Galocha-Ontiñena Unit**

Mapping unit: Lutites and sandstones paleochannels.

Materials belonging to this unit outcrop in the east of the study area. They can be as thick as 25-30 m and are formed by alternance of sandstones layers (0.5-3m) and lutites.

- **Bujaraloz-Sariñena Unit**

This unit outcrops in the middle north-east and represents more than 50% of the Tertiary materials.Mapping units:

- Sandstones paleochannels and lutites; locally micritic limestones
- Micritic limestones, marls and claystones
- Marls with gypsum nodules

- **Remolinos-Lanaja Unit**

This unit outcrops continuously from south-east to north-west.Mapping units

- Lutites and sandstones paleochannels
- Marls, nodular gypsum, sandstones and siltstones

3.3.2.2.2. Quaternary units

Quaternary sediments are spread over most of the study area.

Surface formations:

- *Coarse detritic sediments* (gravels and stones in a silty-clay matrix): 6 levels of glacis They are widespread in the study area, related to the piedmont of the Sierra of Alcubierre. The size of the coarse elements decrease from proximal to distal areas. The 6 levels are differentiated by their relative differences in height.

- *Poligenic coarse detritic sediments* (stones and gravels, river terraces): 4 levels corresponding with the levels of terraces of Flumen and Alcanadre rivers.

- *Fine detritic sediments* (sand, silt and clay with gravels). Alluvial fan or first terrace level in the Flumen and Alcanadre rivers

- *Heterogenic detritic sediments* (stones and gravels in silt and clay matrix). Colluvium, heterogeneous deposits in slopes

- *Fine detritic sediments* (sand, silt and clay with gravel, bottom valleys). Mixed materials of alluvial and colluvial origin.

- *Laminated fine detritic sediments* (clay and silt). Fine detritic sediments with an almost horizontal sedimentary organisation finely laminated

3.3.2.2.3. Comparative studies: lutites vs. fine grained laminated detritic sediments

Lutites of the Sariñena Unit have been characterised using 30 samples taken from stone quarries and fresh cuts (Table 3.3.5).

Weathering, erosion and transport of lutites and sandstones produce a 1-2 m thick covers of finely laminated sediments in slightly-sloping areas and valley bottoms. Analytical characteristics of these sediments are shown on Table 3.3.6.

Lutites are generally saline-sodic, and after weathering, erosion and deposition in finely laminated sediments a sodification process occurs.

Clay mineralogy of these sediments shows the presence of illite with good cristalinity and labile minerals such as chlorite and pyrophyllite and absence of interstratified, expandables and fibritic materials, which point to a low degree of evolution-transformation.

Table 3.3. 5. Lutites characteristics.

SAM-PLE	ECe dS/m 25°C	pH Paste	Cations(meq/l)			Anions (meq/l)			SAR	CLAY MINERALOGY(%)					
										Phyllosilicates					
			Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}		I	Cl	P	Q	F	C
GAB-1	2.01	9.0	2.9	9.1	14.2	14.6	2.9	7.1	5.8	76	3	1	8	2	8
GAB-2	1.42	9.0	1.9	5.1	6.5	7.3	1.9	4.5	3.5						
ALC-1	26.80	8.3	35.4	118.6	133.7	154.5	113.0	5.2	15.2						
TAR-1	6.50	8.1	31.70	42.7	4.30	8.6	65.2	3.1	0.7	76	2	Tr	4	1	17
ALC-2	26.19	8.3	40.1	102.7	135.9	162.5	107.0	2.6	16.1						
TAR-2	26.80	9.2	31.2	76.3	224.8	184.0	139.0	5.5	30.7						
TAR-3	6.09	8.9	13.2	27.2	35.0	64.0	40.4	3.7	7.8						
VIC-1	12.7	9.4	6.1	10.7	148.0	132.0	28.7	8.2	51.1						
VIC-2	6.0	8.8	6.8	16.0	45.2	41.8	14.4	3.8	13.4						
ALB-1	34.4	8.3	15.9	15.3	338.4	252.0	97.6	3.8	85.7						
ALB-2	20.8	8.6	8.83	8.8	205.4	184.0	40.2	8.6	73.5						
ALB-3	30.9	8.5	15.4	23.0	330.8	300.0	53.2	4.1	75.5						
SL-1	32.9	8.2	128.7	87.3	135.2	184.3	147.2	3.4	13.1	62	3	2	9	2	22
PO-1	20.7	8.2	14.6	27.4	167.4	176.0	19.52	2.7	35.6						
PO-2	12.8	8.2	12.2	16.6	88.7	94.5	20.87	1.8	23.4						
GR-1	6.1	8.3	10.5	14.7	38.3	48.3	10.94	3.1	10.8	74	3	1	15	3	4
GR-2	13.4	8.0	41.7	47.7	50.5	68.1	56.4	3.4	7.5						
BAL-1	15.1	9.0	7.8	6.6	136.1	106.7	32.4	8.0	50.7						
GR-3	9.3	8.3	27.1	3.7	60.6	61.6	25.7	5.3	15.4						
ROB-1	80.5	8.8	12.2	104.2	53.0	68.3	100.0	4.8	6.9						
MSU-1	7.65	8.4	15.9	24.7	58.9	46.6	45.5	3.6	13.1						
PO-3	15.4	8.7	2.0	20.0	156.0	158.4	38.0	2.7	47.0						
CU-1	15.7	8.8							38.7	72	4	3	7	3	8
MSO5	4.8	8.5							12.9	60	3	1	11	1	22
SJF11	13.6	7.9	23.0	26.2	105.8	110.0	27.4	2.4	21.4						
SJF12	23.5	8.2	12.5	28.5	222.1	210.0	31.2	2.4	34.7						
SJF13	48.5	8.0	37.0	50.0	565.2	545.0	55.1	2.2	85.7	70	5	1	7	4	12
SJF21	12.2	8.3	10.0	20.5	114.8	90.5	42.1	3.2	29.4						
SJF22	11.8	8.4	5.0	10.5	112.1	85.0	30.2	2.6	39.6						
SJF23	11.0	8.4	6.0	7.5	116.0	84.3	35.4	2.4	44.6						

Phy: Phyllosilicates (I:Illite, Cl:Chlorite, P:Pyrophyllite); Q:Quartz; F:Feldspars, C:Calcite; Tr: Traces.

Table 3.3. 6. Characteristics of fine-grained laminated detritic sediments.

SAM-PLE	ECe dS/m 25°C	pH Paste	Cations(meq/l)			Anions (meq/l)			SAR	CLAY MINERALOGY(%)					
										Phylosilicates					
			Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}		I	Cl	P	Q	F	C
GRA-1	24.36	8.8	6.3	5.7	234.3	198.2	26.8	5.6	95.6	56	2	2	14	4	20
GRA-2	20.10	9.5	6.3	7.3	239.6	176.2	29.5	9.2	91.6	66	2	1	7	6	17
GRA-3	6.8	-	1.9	3.1	70.1	45.5	19.6	5.8	47.5						
LAA-1	4.8	10.0	0.8	1.1	47.0				50.2						
LAA-2	3.3	9.6	0.6	1.0	27.9				33.0						
LA A-3	1.5	9.3	0.4	1.0	16.6				21.5						
LA B-1	1.4	9.2	0.5	0.6	11.9				16.0						
LA B-2	9.6	10.3	2.1	1.6	100.1	53.4	28.8	11.9	73.6						
LA B-3	4.5	10.3	24	2.6	44.2	6.9	16.1	14.3	28.0						

Phy: Phyllosilicates (I:Illite, Cl:Chlorite, P:Pyrophyllite); Q:Quartz; F:Feldspars, C:Calcite.

3.3.2.3. Geomorphology

At regional level, three main landforms have been defined (see Figure 3.3.4):

- **Sierra of Alcubierre structural landforms:**

Structural platforms developed at the top of the highly-carbonatic Neogen series, which are formed mainly by limestones and some calcilutites, sandstones and gypsum.

- **Somontano platforms:**

They are acting as an interfluve between the Flumen and Guatizalema rivers and are the result of landform inversion.

- **Sariñena Depression**

It is formed by the adjustment of the fluvial network in the Sariñena Formation (lutites,mainly

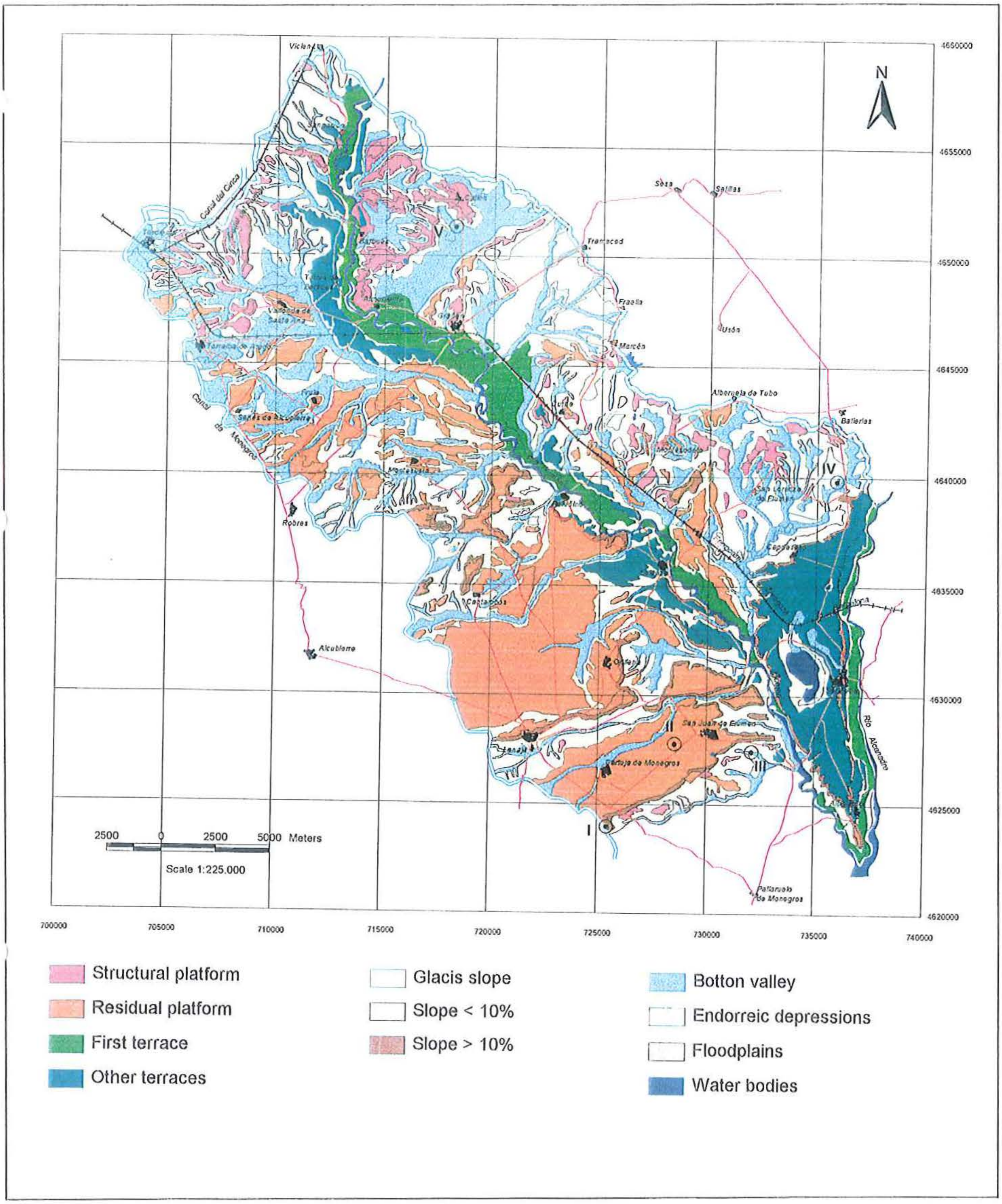


Figure 3.3. 4. Geomorphological map (S 1:225000).

3.3.2.3.1. Detailed geomorphology

Most part of the study area is located within the Sariñena Depression, and five landforms may be differentiate:

- A: Structural landforms
- B: Residual platforms: related to glacis, covered by coarse detritic sediments; local name: "sasos".
- C: Terraces
- D: Slopes: This unit can be divided into 3:
  - D1: Slopes less than 10° steep
  - D2: Slopes more than 10° steep
  - D3: Slopes in glacis

E: Flat areas:
  - E1: Flood plains: Flumen alluvial areas
  - E2: Valley bottoms without stream beds
  - E3: Endorreic depressions

3.3.2.3.2. Present processes

The Wilson (1968) and Peltier(1950) diagrams indicate an absolute predominance of semiarid modelling, in agreement with present processes, and point out to the importance of fluvial erosion, the moderate intensity of physical weathering and the moderate to weak intensity of chemical weathering and eolic erosion.

Present functional processes are rill erosion and stream formation, specially in the area of Sierra of Alcubierre because of the strong slope gradient and the gully network. In the irrigated area, present processes are conditioned by anthropic activity and involve gully and piping erosion and mass movements.

In the Sariñena Depression, piping affects the Miocene lutites and fine detritic sediments, mainly in slopes, in the bottom valleys and in irrigation levelled plots that have been abandoned. The main factors that increase the process are (Gracia Prieto, 1986; Gutierrez and Rodriguez, 1984) high silt content, sodicity, low structural stability, geologic materials and semiarid climate. Areas strongly affected by gully-piping processes are: El Barranco de las Lastras (Grañen), El Boral (Montesodeto, Poleñino (Lalueza), El Matical (S. Juan de Flumen), Monte Rufas (Callén),....

Evidences of deflaction and sedimentary wind features have not been found in the study area neither as actual process nor as ancient process.

Haloclastic weatering processes promote sand formation from sandstone fragments in slopes. This fact explains the low clast frequency in local sediments. In carbonate-cemented sandstones alveolar erosion ("tafonización") processes are observed.

3.3.2.3.3. Geomorphological dating

Terraces and glacis levels identified in the area allow an approximate chronology. Available data suggest that terrace levels are not related to cold glaciation periods, as these have not been identified in the Pyrenees. Other considerations such as tectonic character and fluvial dynamics make correlation even more difficult (Rodriguez-Vidal, 1986)

Datings have been performed by archeological methods, in valley bottoms and slopes. Rodriguez-Vidal, (1986) considered that the lower terrace level (T1), valley bottom valley and regularized slopes date from Medieval times.

Palinologic studies on fine-grained laminated materials at 1.8 m, indicate the presence of an association of *Chenopodiacea* and *Pinus sylvestris*; at 40 cm depth *Cerealia* was present.

3.3.2.4. Hydrology

3.3.2.4.1. Hydrogeologic characteristics.

The study area is located in the lower valley of Flumen river and in a small part in the Alcanadre river watershed. The drainage network has developed in a fishbone pattern in relation to the Flumen River. The right side shows thin and long valleys, but some wider valleys are also present, as Callen, Matical, etc. Endorreic areas also exist, e.g. the Sariñena Lake.

There is no groundwater system at regional level, but there are some hydrogeologic formations of importance at local level.

3.3.2.4.2. Irrigation and drainage network.

There is a main canal (Canal de Monegros) which irrigates the right side of the Flumen River, and Canal de Flumen which irrigates part of the right and the left side of Flumen River.

Flood irrigation is the most widespread system and usually plots are smaller than 1 ha. Lately, sprinkler irrigation has been established in some areas.

There is water seepage at regional level from the upper parts (platforms -"sasos"-) to the bottoms; at detailed scale, the same occurs between plots. At the upper parts hydraulic conductivity and infiltration rate values are high; available soil water holding capacity is low because of the presence of many coarse fragments; because of all these factors, irrigation efficiency at plot level is low.

The water excess with high soluble salt content has driven salinization to the lower parts.
At plot level there are few drainage networks and in many cases they are not functional due to siltation.

3.3.2.4.3. Chemistry of water.

Irrigation water comes from the Pyrenees, from River Gallego through Canal de Monegros. Electrical conductivity varies from 0.23 to 0.87dS/m at 25ºC (0.46±0.20dS/m), SAR is 0.5 and pH is equal to 8.0 with a minimun variability. Groundwater properties (Table 3.3.7) depend on the characteristics of the geologic and pedologic materials through which water flow.

Table 3.3. 7. Groundwater characteristics (EC, SAR) depending on geomorphological position.

	RESIDUAL PLATFORMS		GLACIS SLOPES		OTHER SLOPES		BOTTOMS		TOTAL	
	Mean	Standard desviation	Mean	Standard desviation	Mean	Standard desviation	Mean	Standard desviation	Mean	Standard desviation
Number of samples	10		22		26		37		95	
Depth (cm)	122	41	132	59	137	52	124	57	129	54
EC (dS/m)	2.08	1.36	5.27	5.93	6.94	6.88	18.75	16.99	10.43	13.2
SAR	8.3	10.5	21.1	15.8	24.7	23.5	62.4	65.3	32.0	30.9
% of samples with pH>8.4	10		50		27		35		34	

Groundwater samples have been grouped in four irrigation-water evaluation classes according to their suitability for irrigation:

- **Useful** (0.5<EC<1.5; SAR<2 and pH<8.5): Only 5% of the water samples did not present any limitation to agronomic use. They are usually located in residual platforms, and are not present in bottoms and slopes.

- **Limitations due to incipient mineralization** (1<EC<3, SAR<12 and pH<8.4): Even if these samples are not saline and would not give infiltration problems, they are not potentially useful due to high sodium and chloride levels that can produce moderate or severe phytotoxicity problems. They appear in glacis and residual platforms and their use should be limited to well drained soils and tolerant crops.

- **Infiltration limitations** (EC<4dS/m, SAR<40 and pH<8.4): This kind of water can potentially create infiltration problems in all geomorphologic units but they are not frequent in slopes.

- **Salinity limitations** (EC>3dS/m, SAR>5 and pH>7.8): These samples represent 30% of total samples, and they are present specially in slopes and bottoms and they have not been found in residual platforms.

3.3.2.5. Vegetation

The potential climax vegetation in Flumen-Monegros area is within the domain of *Rhamno-Quercetum cocciferae cocciferetosum* (Braun-Blanquet and Bolòs, 1957). In the area located north of the Robres-Cantalobos-Poleñino-Capdesaso line, the potential vegetation belongs to *Bupleuro rigidi Quercetum rotundifoliae* series.

This climatic vegetation has been strongly degraded because of the traditional human pressure (fire, cropping, ...) and by the impact of irrigation (Rodríguez, 1998) and now only a few isolated samples of *Quercus coccifera* remain.

As a result of agricultural activities, nitrophilous, higrophilous and halophilous communities are important in the landscape (Herrero *et al.* 1989). The nitro-halophilous *Salsolo-Peganion* shrubs appear in rainfed and irrigated non-saline conditions in field borders and abandoned plots.

The *Phragmitetea* and *Molino-Arrhenantetea* classes appear associated to irrigation channels, seepages and field borders.

Halophilous communities are present as a result of ecological soil conditions: high salinity and sodicity levels, watertables,... and originate different communities that are useful as indicators of pedologic condition (Herrero, 1981; del Santo and Rodriguez, 1991).
There are also ome small afforestations with *Pinus halepensis* in the area.

3.3.2.6. Land use

In the Flumen-Monegros Area maize, alfalfa, wheat, sunflower, ray-grass and barley are the main crops. The latter is predominant in more saline soils. The considerable extension of soils with salinity and sodicity problems has driven to rice monoculture in some areas and the establishment of temporary grassland and forages.

Fruit orchards are few and basically for to self-consumition (Rodríguez et al., 1989). Vegetables have been introduced in recent years in platforms ("sasos"), but their hectarage is limited by the lack of reliable markets; onions, peppers, pea, green beans, glasshouse crops... are the main crops.

Rice is considered as an alternative crop that has been introduced in association with the irrigation system. It is found at the bottom areas with salinity and sodicity problems, due to its assumed capacity to improve saline soils. It would be necessary to contrast this view with local experimentation.

Soils with natric horizons are used mainly for alfalfa as the most cost-effective crop, even if maximum productions are not obtained.

Rainfed crops are winter cereals (mainly barley and wheat), almonds, vineyards and olive trees.

3.3.3. Soil-landscape relationships

3.3.3.1. Introduction

During the 1970s various soil studies were conducted in the area:

The first pedological study in the area was undertaken by SOCINCO (1974). 4 500 ha were selected and studied as representative of 40 000 ha within the irrigation system.

Other studies were done by INYPSA (1975) in the Flumen irrigated area, and INTECSA (1975) in the 2nd and 3rd sectors of Canal de Monegros. In all, some 62 000 ha were studied, 30% of which had salinity problems, another 30% had salinity-sodicity problems, and 3% were affected by sodicity.

3.3.3.2. Basic information and methodology

The basic information used to do this work has been a set of aerial photographs at different scales and dates:

- Flight USAF-A (1947): approximate scale 1:42000, used in some sectors
- Flight USAF-B (1956): approximate scale 1:33000, for all the study area.
- Flight M.A.P.A. (1978): scale 1:18000, used in model areas

This information was complemented with topographic maps from IGN (Instituto Geográfico Nacional) at 1:25000 and 1:50000 scales.

Apart from the classical work of air-photo interpretation, the comparision between years has been useful to detect levelling works.

Fotointerpretation has been made repeatedly with field prospection to check information in the two ways.

During the field work, 170 soil pits and auger-holes were described following the SINEDARES (CBDSA, 1983) and CatSIS (DARP, 1993) criteria.

Some laboratory analyses were performed to all the samples: EC1:5, pH, organic matter, % $CaCO_3$,... On profiles with salinity-sodicity problems soluble anions and cations were determined in the saturation extract

From some profiles undisturbed samples were taken and soil thin sections made following Guilloré (1985) methodology and described with morphoanalytical criteria proposed by Bullock *et al.* (1985).

Some soil model areas were studied more intensively for different goals:

- San Lorenzo and Curve (9% of the study area)at 1:50000 scale in order to understand and map in detail soil-landscape relationships.
- Torres de Barbués (NW Grañen, 4% of the study area) at 1:25000 scale for land evaluation (Nogués et al, 1996).
- For specific problems (salinity, sodicity, drainage pipe silting....). These surveys are described in more detail in section 3.3.4.

3.3.3.3. Mapping units

We developed a physiographic soil-map legend with a landform entry.

The basic mapping units are consociations of subgroups of Soil Taxonomy whenever possible, and associations or complexes in other cases. Dominant and minor soil subgroups found at each physiographic unit are shown on Table 3.3.8.

Table 3.3. 8. Map legend units in the study area, (SSS,1994).

Physiographic soil units		**Dominant soil subgroups**	**Minor soil subgroups**
Structural platform		Xeric Torriorthent Lithic-Xeric Torriorthent	Xeric Haplocalcid
Residual platform	Dissected glacis slopes	Xeric Petrocalcid Xeric Haplocalcid	Calcixerollic Xerochrept Petrocalcic Xerochrept
	Other terraces	Xeric Petrocalcid Xeric Haplocalcid Calcixerollic Xerochrept Petrocalcic Xerochrept	Calcic Haploxeralf Aquic Xerochrept Xeric Petroargid Xeric Calciargid
	1st terrace	Typic Xerofluvent Oxyaquic Xerofluvent	Xeric Torriorthent Fluventic Xerochrept Typic Xerorthent
Slopes	Glacis slopes	Typic Xerofluvent Calcixerollic Xerochrept	Fluventic Xerochrept Typic Natrixeralf Xeric Torriorthent Typic Xerorthent
	<10°	Typic Xerofluvent Oxyaquic Xerofluvent Fluventic Xerochrept Xeric Torriorthent	Typic Natrixeralf Typic Xerorthent Oxyaquic Xerorthent Calcixerollic Xerochrept Typic Natrargid
	>10°	Xeric Torriorthent	Typic Xerofluvent Typic Xerorthent Typic Natrargid
Bottoms	Valley bottoms	Typic Xerofluvent Oxyaquic Xerofluvent	Typic Haplosalid Fluventic Xerochrept Gypsic Xerochrept Xeric Torriorthent Aeric Fluvaquent Typic Xerorthent
	Endorreic depressions	Typic Xerofluvent Oxyaquic Xerofluvent	Aquic Xerochrept Typic Xerorthent Xeric Torriorthent
	Floodplains	Typic Xerofluvent Oxyaquic Xerofluvent	Xeric Torriorthent

3.3.3.4. Taxonomic units

The following taxonomic units have been identified in the mapped area; characteristics at the family level are also presented in Table 3.3.9.

Table 3.3. 9. Taxonomic units in the study area, (SSS,1994)

Subgroup classification	**Other characterists at the family level**
Aeric Fluvaquent	Coarse loamy, mixed (calcareous), thermic
Lithic-xeric Torriorthent	Loamy, mixed (calcareous), thermic, shallow
Xeric Torriorthent	Fine, coarse or fine loamy or fine silty, mixed (calcareous) thermic, shallow or not
Oxyaquic Xerofluvent	Fine or fine loamy or fine silty, mixed (calcareous), thermic
Typic Xerofluvent	Fine, fine or coarse loamy, fine or coarse silty, mixed (calcareous), thermic
Typic Xerorthent	Fine, coarse or fine loamy, mixed (calcareous), thermic
Oxyaquic Xerorthent	Fine loamy, mixed (calcareous), thermic
Xeric Haplocalcid	Loamy-skeletal, carbonatic, thermic, shallow (or not)
Xeric Petroargid	Loamy-skeletal, carbonatic, thermic, shalow
Xeric Calciargid	Loamy-skeletal, carbonatic, thermic, shalow
Xeric Natrargid	Fine or fine loamy, mixed, thermic
Xeric Petrocalcid	From loamy-skeletal to coarse loamy, mixed or carbonatic, thermic, shallow
Typic Haplosalid	Fine loamy, mixed, thermic
Aquic Xerochrept	Fine or loamy-skeletal, carbonatic or mixed, thermic
Calcixerollic Xerochrept	Fine or coarse loamy, mixed, thermic
Fluventic Xerochrept	Fine loamy or loamy-skeletal, carbonatic or mixed, thermic
Petrocalcic Xerochrept	Fine loamy, mixed, thermic
Gypsic Xerochrept	Fine loamy, gypsic or carbonatic, thermic
Typic Natrixeralf	From loamy-skeletal to fine, mixed, thermic
Calcic Haploxeralf	Loamy-skeletal, carbonatic, thermic

3.3.4. Transformation from rainfed land to irrigated

3.3.4.1. Impacts associated with irrigation

The rainfed to irrigation transformation has involved some different impacts in the Flumen-Monegros area. In Table 3.3.10, most of the impacts detected are shown.

Table 3.3. 10. Type of impacts linked to irrigation transformation in the Flumen-Monegros area.

	DETECTED EFFECTS
Socioeconomic and sociological	- Ten new villages were created, that were called "colonisation villages". - Settlement of 2000-3000 people from different geographic areas (villages in the Pyrenees flooded by dams, agricultural workers from Andalucía,...) - Introduction and technologic adaptation of new crops: rice by Ebro-Delta farmers, sugar beet, maize, pepper, onion, tomatoes, intensive glasshouse crops,... - Development of co-operatives: ATRIA Rice, Monegros Co-operative, Hortícola,...
Perceptual	- Systematic landscape modifications, mainly in slopes - Afforestation of non-cultivated areas, more than 1000 has.
Biologic	- Vegetation. Expansion of some vegetation types: hygrophilous, halophilous, rice weeds and ruderal plants related to irrigated conditions. - Reduction of Mediterranean vegetation (bush,...) - Fauna: Increase and diversification of migratory birds. Decrease in habitats for steppic species.
Crops(*)	- Change from rainfed agricultural system to an irrigated one. - More reliable yields - Increase in productivity in many cases (higher yields) - Diversification of the cropping system - Animal husbandry: Increase in the carrying capacity (sheep) Introduction of intensive animal production
Non preservation of topsoil during land levelling and deep ploughing	- Destruction/alteration of soil profile - Epipedon losses - Mixture of pedogenic and non-pedogenic materials - Underlying materials brought up to the surface, even petrocalcic horizons. - New layout of plots: soil heterogeneity within plots; problems in irrigation management, fertilization, ploughing depth,... - Difficulties to model soil-landscape
Change in hydrologic conditions	- Low efficiency in the use of irrigation system. - Seepages in slopes and bottom areas. - Creation/elevation of saline groundwater tables. - Increasing conflict by water use - Water quality degradation in hydrologic systems: salts, nitrates, pesticides, sediments,...

(*) These processes will be further discussed because they are specially relevant.

Table 3.3.10 (continuation). Type of impacts linked to irrigation transformation in the Flumen-Monegros area

Soil salinization (*)	- Salinization os valey bottoms and slopes: origin and condicionants
Soil sodification and structural instabilization (*)	- **Structural degradation of the arable layer** - Decrease in Infiltration rates - Decrease in plant available water - Limitations to crop emergence and establishment - Defficient root exploration - Surface crust formation - Increase in runoff - **Structural degradation of subsurface horizons** - Low hydraulic conductivity - Soil aeration problems - Increase in soil mechanic impedance - **Translocation of solid material (*)** - Dispersion and/or illuviation of sodic clays - Movement of clay, silt and sand in variable proportions - **Silting of underground drainage system (*)** - Porosity degradation in the material filling the installation ditches of underground drainage - Infilling of drainage-pipe cover - High rates of translocation of solid materials - **Degradation of:(*)** - Irrigation water delivery system - Open-air drainage ditches - Road network, public works,... - Limitation to trafficability, ploughing and irrigation operations - Abandonment of Irrigated land - Erosion processes (*): gully-piping and mass movement.

(*) These processes will be further discussed because they are specially relevant.

3.3.4.2. Changes in land use (Stop 2)

The main positive impact of the transformation is the introduction of many new crops which could not be grown under rainfed conditions, income from these crops is much higher than that from rainfed crops and as a result new population settlements are developed.

In the geomorphologic units of residual platforms -"sasos"-, the main soil type is represented by Pedon 2SANJUAN.(Appendix 3.3)

In this soil unit there are not salinity problems and the main crop is maize, with yields varying from 8000 to 11000 kg ha^{-1}. Maize management is well-known by farmers and associated problems are related to insect attacks as *Sesamia,...* Usually maize is cropped in rotation with lucerne and wheat.

Lucerne, "Aragón" ecotype, is the most cultivated forage in the area. It stands on the plot for 4-5 years and is followed by winter cereal (usually wheat). Lucerne is cut 4-5 times each year and mean annual production in this soil unit is about 14000 kg of dry matter ha^{-1}. Water requirements (rainfall and irrigation) for lucerne are about 1000 mm per year, which is very high as against other crops (maize about 600 mm per year,...), and the main climatic limitant factor is the low temperature in spring.

Lucerne is also used in other soil units as a soil improving crop, because of its ability to incorporate organic matter and increase structural stability. Also lucerne allows a downward flow during almost all the year which helps to prevent from re-salinization.

Wheat is used in crop rotations, usually after lucerne and its production in this unit is about 3000-4000 kg ha^{-1}.

This is the only major soil unit of the area where vegetables are cultivated. From last eighties to now vegetable crop are increasing and some years up to 500 ha have been used for onion, tomatoes and pepper to be canned.

Plastic greenhouses have been installed close to San Juan de Flumen village where fresh vegetables (beans, courgettes, eggplants, borage,...) are cropped.

The associated problems in this unit is related to irrigation efficiency. Because of the high coarse element content the low rooting depth and the low water holding capaticy, there are high water losses by seepage, which induced salinization in the lower positions.

3.3.4.3. Soil salinity (Stop 3.2)

In the Flumen-Monegros irrigation system almost 60% of the soils were affected by salinity in 1975 (INTECSA, 1975; INYPSA, 1975), and 50% of them presented also sodicity problems.

Soils on residual platforms (sasos) have shallow rooting depth, high coarse-fragment content and low water holding capacity which force frequent irrigations and give high water losses. Water flows lateraly from higher geomorphologic positions to lower ones carrying soluble salts and leading accumulation in the valley bottoms. The natural drainage network which had small gullies, was also modified during the transformation and, as a result, drainage and salt control has become very difficult.

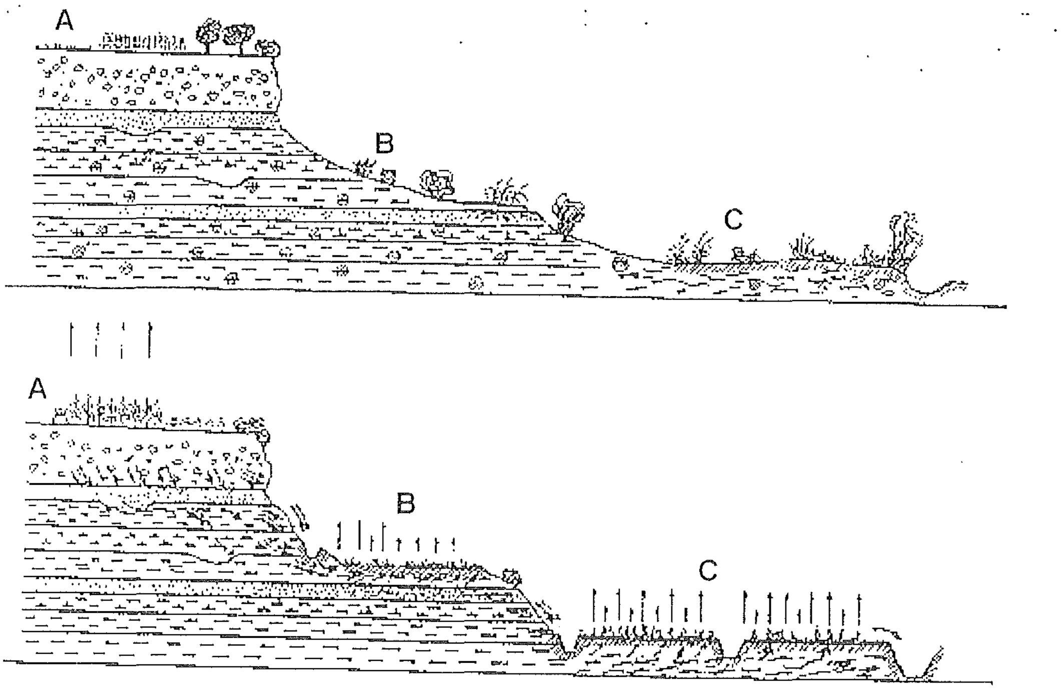


Figure 3.3. 5. Landscape transformations due to irrigation.

Units B and C (Figure 3.3.5) are now affected by salinity-sodicity problems in different way, induced by non topsoil preservation during land levelling and antropic change in hydrological conditions. The parent material (saline lutites) together with the irrigation technology used (flood irrigation in levelled plots without topsoil preservation) and the lack of a functional drainage network has favoured the processes.

3.3.4.3.1. Origin and distribution of salinity

A study was carried out in order to establish the relationships between water geochemical characteristics and its landscape dynamics under irrigation conditions. Sampling was made at different landscape positions: canal irrigation water, "saso" groundwater table, seepage water from the "saso", drainage water from slopes, levelled slope groundwater and drainage water from valley bottoms (Figure 3.3.6).

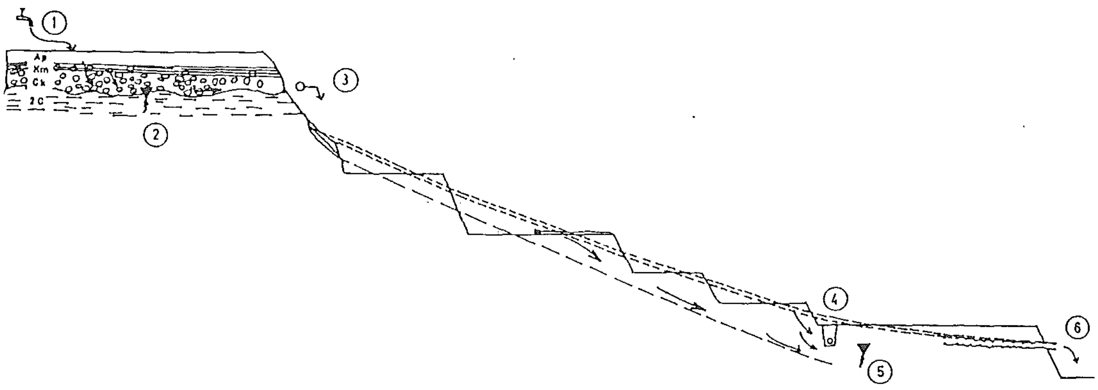
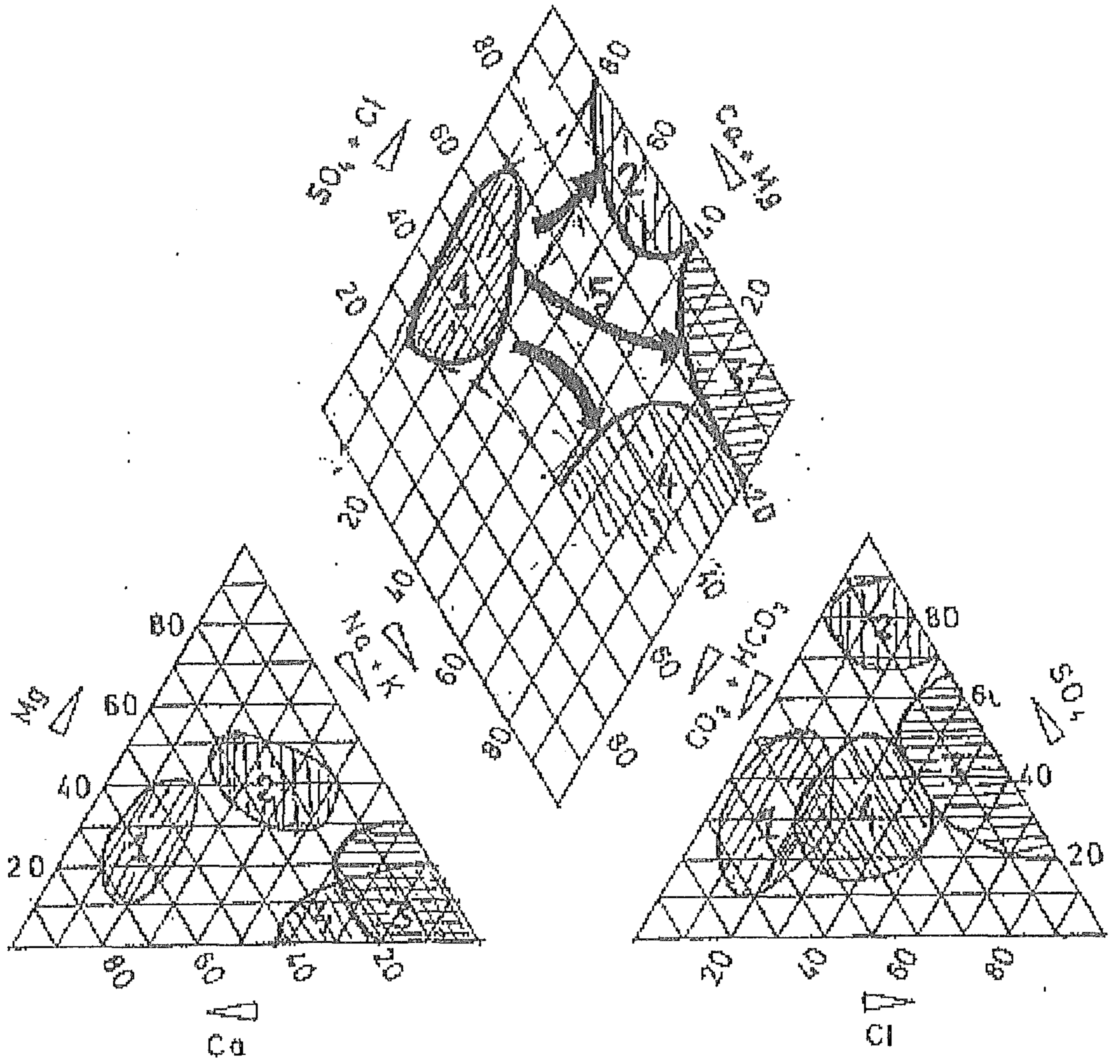


Figure 3.3. 6. Scheme of water sampling. ① canal irrigation water, ② "saso" groundwater table, ③ seepage water from the "saso", ④ drainage water from slopes, ⑤ levelled slope groudwater and ⑥ drainage water from valley bottoms.

Soil salinity in the Flumen-Monegros Area comes from the parent material of soils.
Water electrical conductivity (EC) increases up to 200 times from canal to valley-bottom water, which summarizes the saline mineralization process through the toposequence; Sodium content increases, from 0.3 cmol/l in irrigation water to 600 cmol /l in valley-bottom drainage water. In the same way, chloride content increases from 0.5 cmol/l to 700 cmol/l. On the other hand soluble carbonates are barely detected.

Hydrogeologic model: redistribution of salts from the groundwater. Pipper diagrams are used to characterize the gechemistry of water (Figure 3.3.7)



Group 1: Fresh water. Dominance of Ca^{+2} and HCO_3^- Group 2.Ground water. Dominance of Na^+, Ca^{+2}, Mg^{+2} cations and SO_4^{-2} and Cl^- anion. Group 3.Ground water. Dominance of Na^+ cation (and sometimes Mg^{+2}) and Cl^- and SO_4^{-2} anions (and sometimes HCO_3^-). Group 4.Ground water.Dominance of Na^+ cation and Cl^-, SO_4^{-2} and HCO_3^- anions. Group 5.Transitional. A transitional area between the 3 cited above.

Figure 3.3. 7. PIPPER diagram.

From the irrigation water (group 1) there is a trend to four types of salinity composition due to geochemical evolution. These characteristics depend on the salinity of the Tertiary materials and Quaternary sediments.

Related to the different geochemistry of saline water, different mineralogical types of soluble salts have been identified in efflorescences and laboratory made accumulations by micromorphology and SEM (scanning electron microscopy) and are presented in Table 3.3.11.

Table 3.3. 11. Minerals found in natural (N) and laboratory-made (L) salt accumulations (Vizcayno et al. 1995)

Name	Formula	Morphology	Location	Type
Bloedite	$Na_2Mg(SO_4)_2.\ 4H_2O$	Prismatic idio-and subidiomorphic	AL-SJ	N
		Foliated rosette-like	AL-SJ	N
		Rounded. Prismatic radiating	AL-SJ	N
		Cementing agent	AL	N
Burkeite	$2Na_2SO_4.Na_2CO_3$	Spheroidal. Book plates	CA	N, L
Epsomite	$MgSO_4.7H_2O$	Prismatic	AL-SJ	L,N
Glauberite	$Na_2SO_4.CaSO_4$	Needle-shaped	MA-SJ	N
Gypsum	$CaSO_4.2H_2O$	Cubic	MA-AL	N
		Needle-shaped	MA-AL	N
		Prismatic	MA	L
Halite	NaCl	Cubic	AL-CA	N, L
		Needle-shaped	AL	N
		Cementing agent	MA-AL-CA-TA-SJ	N
		Fibrous prismatic	MA	N
Hexahydrite	$MgSO_4.6H_2O$	Prismatic. Acicular	AL-TA	L, N
Konyaite	$Na_2Mg(SO_4)_2.5H_2O$		AL-SJ-TA	N, L
Mirabillite	$Na_2SO_4.10H_2O$	Prismatic	MA-SJ	N, L
		Serrated edged rods	MA	N
Natron	$Na_2CO_3.10H_2O$	Prismatic subidiomorphic	CA	N
Thenardite	Na_2SO_4	Pseudomorphic after mirabillite with drusy-like	MA-SJ	N
		Rossette-like	MA-AL-CA-TA	N, L
		Needle-shaped	CA	L
		Lenticular. Anhedral	MA	N
		Nodular	MA-CA	N
Thermonatrite	$Na_2CO_3.1H_2O$	Pseudomorphic after natron	CA	L
Trona	$Na_2CO_3.NaHCO_3.2H_2O$	Bars in radiating fans	CA	N, L
		Needle-shaped	CA	N

Marcén (MA), Almuniente (AL), Callén (CA), San Juan (SJ) and Tardienta (TA) areas.

3.3.4.3.2. Soil salinity-sodicity mapping

Cartography of soil salinity-sodicity has been undertaken in two steps:

Step 1: Using a classical approach to soil mapping. The SINEDARES description criteria (CBDSA, 1983); FAO (1998) and SSS (1975, 1994) classification an estimate of salinity affected areas was obtained at 1:100.000 scale

Affected soils were define as a subgroup phase, except in the case of soils with a natric horizon. Three parameters were considered:

Salinity: Electric conductivity of the saturation extract (ECe dS m^{-1} a 25° C).
Sodicity: SAR (sodium adsorption relation) and ESP (exchangeable sodium percentage).
Alkalinity: pH (1:2.5) and pH in saturation paste..

At this level, almost 40% of the study area has salinity and/or sodicity problems (Table 3.3.12).

Table 3.3. 12. Area affected by salinity-sodicity problems (% and ha) in Flumen-Monegros.

Affection	%	ha	CE (dS m^{-1}); ESP ranges
No salinity-sodicity problems	46.4	28934	CE<4 and ESP<8.4
Slight salinity and/or sodicity problems	24.5	15256	4<CE<16 and ESP<15
Moderate to strong salinity and sodicity problems	14.1	8775	CE>4 and ESP>15 or CE>16;
Non irrigated areas	14.6	9137	-

Soil salinity-sodicity distribution is defined by landscape units. The upper positions (structural and residual platforms) are characterized by the lack of salinity-sodicity problems. In glacis slopes there are saline, saline-sodic, sodic and non-saline soils, depending upon soil texture and hydrogeologic factors. Finely -textured soils are the ones most affected by salinity problems.

In modified slopes, levelling has left lutites very close to the soil surface, and this material has led to salinity problems.

In medium and bottom parts of the slopes, salinity and sodicity processes have created important problems to the agricultural land use.

The soils of the best quality for agriculture in the area are in the alluvial fan of the Flumen river, they have been irrigated for centuries and only slight salinity problems have developed in the southern part.

The valleys bottom in the area are affected by salinity in most cases. However, there are some areas (Senés, Torralba, Tardienta) where the presence of gypsum in the parent material has slowed down the sodification process.

In depressions as Callen and Sariñena, soils have important salinization and sodification processes. In these areas many fields have been abandoned and rice is the only crop grown.

Step 2:

The step 1 approach only allowed the assignment of a salinity-sodicity class to each mapping unit and no information was available about spatial and temporal variability inside the mapping units. In step2 salinity measurements with the electromagnetic sensor (EMS) in different years coupled with geostatistical methods were applied to some model areas (Salazar et al, 1996).

For EMS calibration, the simple linear regression model is useful in our situation, and the best results are obtained with horizontal configuration and considering an integration depth of 1.2 m, because of the inherent characteristics of the equipment. The measurement is influenced by the sudden change in moisture content when a groundwater table exists, but this can be corrected by putting up the sensor into a vertical configuration.

In reference to the geostatistical data treatment, the maximum ECe obtained from EMS readings gives results that through a correct interpretation can be adecuated to take a decision in management and/or recuperation of these saline soils.

Mapping with EMS saves time and economic resources since the need for laboratory analyses is reduced. High quantity of good-quality information is obtained. The geostatistical treatment of this information produces a new spatial model of salinity that can be used in evaluation and monitoring programs.

3.3.4.4. Gully and pipe erosion (Stop 3.1)

In the Sariñena Depression piping acquires high intensity and affects Miocen lutites as well as fine detritic sediments. Piping processes are located mainly at valley bottoms and slopes.

Low yields and other management problems in fields located in these areas has led to their abandonment, and gully and piping processes have developed (Herrero et al., 1989;

Rodriguez and Porta, 1994). Piping erosion also occurs when the land is cultivated, but farmers repair systematically the problematic points and avoid bigger problems, but the process is accelerated when the plot is abandoned. Other problems associated are:

- Soil losses
- Loss of crop land (more than the affected area)
- Filling up of drainage trenches
- Delivery of sediments to other parts of the hydrologic system: silting of dams,...

A study was conducted (Pratdesaba, 1997) with the purpose of knowing local pipe erosion control factors and generate a hypothesis about the genesis of the erosion process.

In an affected plot, eroded volume was measured with topographical techniques. Three areas with different degrees of erosion were defined. Soil losses at each one are shown on Table 3.3.13. Considering the whole plot, gully and piping soil losses had been at least 1356 Mg ha^{-1} during the 30 years after abandonment.

Table 3.3. 13. Soil losses in the three subplots during the period 1965 (abandonment of the plot) and 1995.

	Subplot1	Subplot2	Subplot3	Whole plot
Soil losses (Mg)	156.7	144.2	46.8	347.7
Soil losses (Mg ha^{-1})	1990	1897	965	1356
Soil losses (Mg ha^{-1} $year^{-1}$)	66.3	63.2	32.2	45.2

Methilen blue was used to trace the water flow paths in those soils. After its application the soil profile was described together with the pipes and the sand translocations associated to them.

Analyses made in laboratory were: satured paste (pH, CEe, soluble cations and anions), organic matter, texture and structural stability test. Some of the soil pits results are shown on Table 3.3.14, and Table 3.3.15 shows some characteristics of surface crusts.

Table 3.3. 14. Analytical results. Means of 4 soil pits.

	Surface horizons		Subsurface horizons	
	Mean	Standard desviation	Mean	Standard desviation
pH paste	8.8	0.8	9.0	0.7
Organic matter (%)	0.7	0.3	0.4	0.1
SALINITY				
CEe (dS/m) 25°C	14.3	18.4	6.0	3.6
SAR	131.5	204.6	59.1	17.2
TEXTURE				
Sand (%)	41.2	10.1	44.1	25.8
Silt (%)	36.4	8.4	34.9	16.0
Clay (%)	22.4	4.5	21.1	10.1

Table 3.3. 15. Characteristics of surface crusts.

	Mean	Standard deviation
pH paste	7.7	0.4
Organic matter (%)	1.8	0.9
SALINITY		
CEe (dS/m) 25°C	17.8	8.2
SAR	40.3	10.9
TEXTURE		
Sand (%)	25.9	10.8
Silt (%)	48.5	11.8
Clay (%)	25.6	5.0

Some undisturbed samples were taken. Their micromorphological study confirmed the high transport capacity of the process and the presence of sand translocations with origin in the levelling process as well as in lutites.

Structural stability was determined by 2 methods: Pierson & Mulla (1989) and Emerson test (1967). The second one is qualitative, but useful for samples the first method cannot handle.

From all the above-mentioned studies, the most important conclusions obtained are:

- The process is favoured by a high hydraulic gradient, which is enhanced by the presence of terraces or land levelling.

- The development of the pipes takes place from an outlet in the edge, but also inside the plot, and it is no need of a well developed connection between them at the beginning of the process.

- The main factor is the presence of dispersive materials or materials with a high structural instability due to the presence of sodium in the exchange complex (ESP between 24 to 61).

- Factors favouring vertical anisotropy in water movement are also important: cracked surfaces, tensional cracks, levelling-material discontinuous, presence in the profile of finely laminated sediments,...

- Pipe morphology in the profiles is controlled by the type of material. In levelling material, pipes are of centimetric diameter, discontinuous and form a complex network. In undisturbed lutites milimetric paths develop usually with vertical direction.

Another area with abandoned plots and erosion problems exists in San Juan de Flumen. A soil pit was described, sampled and analysed and will be visited during the field trip (3VERTIENTE, Appendix 3.3).

3.3.4.5. Silting of the drainage system (Stop 4)

Because of the salinity and sodicity problems enhanced by land levelling and irrigation, an experimental field drainage scheme was designed (INYPSA, 1975) and applied in two plots (San Juan y San Lorenzo de Flumen), to study the efficiency of two types of drainage pipes and several types of drain envelopes (Table 3.3.16)

Table 3.3. 16. Pipe and envelope combinations.

Pipe	PVC	PVC	PVC	PVC	PVC	Ceramic	Ceramic	Ceramic
Internal ∅	44mm	44mm	44mm	44mm	44mm	80mm	80mm	80mm
Envelope	Gravel	Coconut Fiber	Esparto	No cover	Straw	No cover	Gravel	Coconut Fiber

Operations performed for dranaige placement were: mechanical excavation of trenches, placing of pipes and envelopes, and re-filling of trenches.

In the San Lorenzo and San Juan plots, a gypsum amendment was applied at a rate of 2 Mg ha^{-1}. The drainage system became non-functional in less than 5 years at the first location (San Juan) and was silted with the first irrigation in San Lorenzo, where it was cleaned with pressurised water and after the second irrigation it was silted again and abandoned. Several studies in the field (Muñoz, 1991; Rodríguez, 1998) and the laboratory (Porta et al, 1996) have been carried out in order to determine the siltation causes.

In this paper results from the San Lorenzo plot are shown. Eleven soil pits were opened, they were described and sampled (disturbed samples for chemical and physical laboratory analyses and undisturbed samples for micromorphological studies). Samples were taken from: undisturbed soil, material filling the trenches, envelope material and silting material (Figure 3.3.8).

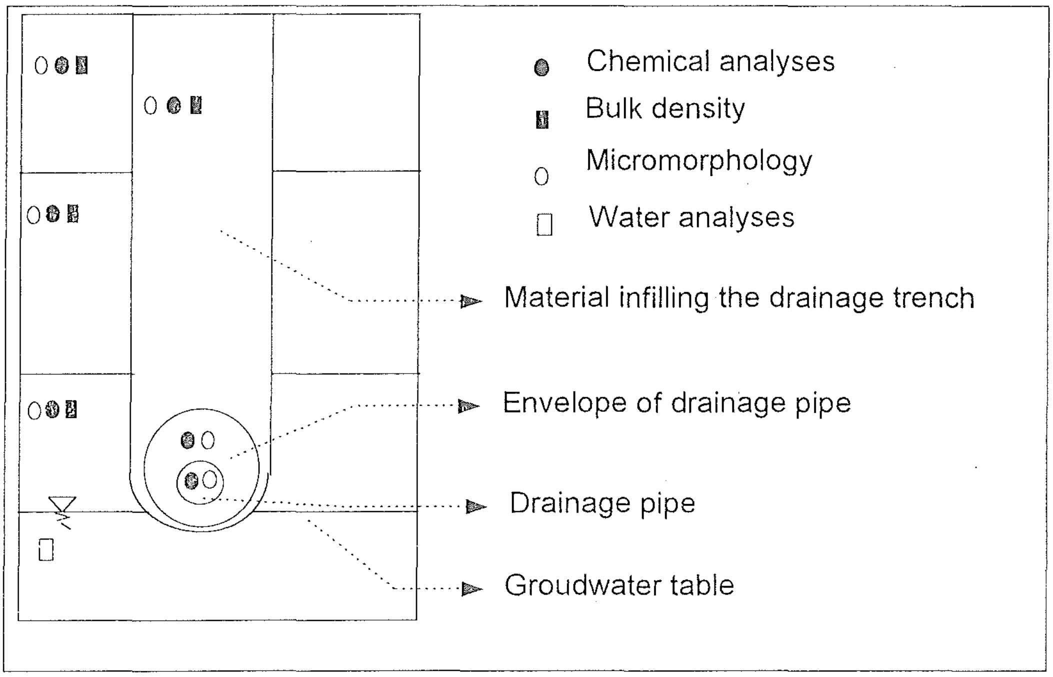


Figure 3.3. 8. Sampling scheme.

Laboratory analyses performed were: satured paste (pH, CEe, soluble cations and anions), organic matter, texture and water retention at -1500 kPa and -33 kPa. At field, measures of hydraulic conductivity were realised.

Thin sections were made (Guilloré, 1985 methodology) and described with polarisation microscopy (Bullock *et al.,* 1985), scanning electronic microscopy (SEM) techniques and microanalysis.

The more relevant analytical results are shown on Table 3.3.17.

Table 3.3. 17. Analytical results from surface and subsurface horizons. Mean of 11 soil pits.

	Surface/s horizon/s		Subsurface/s horizon/s	
	Mean	Standard deviation	Mean	Standard deviation
pH				
pH water 1:2.5	9.1	0.9	9.3	0.8
pH paste	8.5	1.0	8.7	0.7
Organic matter	0.8	0.5	0.6	0.3
SALINITY				
CE 1:5 dS m^{-1} at 25°C	0.5	0.3	0.4	0.2
CEe dS m^{-1} at 25°C	2.3	1.1	2.5	0.1
SAR	11.4	11.8	12.7	6.4
Ca^{2+}/Mg^{2+}	4.2	7.3	3.8	3.0
TEXTURE				
Sand (%)	25.6	17.8	20.1	18.1
Silt (%)	52.9	16.1	56.3	16.4
Clay(%)	21.5	8.6	23.6	14.7
Water retention $_{-33Kpa}$ (%)	31.8	7.0	31.2	11.6
Water retention$_{-1500Kpa}$ (%)	8.7	13.0	9.2	4.3
Hydraulic conductivity K (cm day^{-1})	5.43	3.17	9.30	5.03

In relation to the performance of the different pipe envelopes: vegetal envelopes were strongly decomposed, except coconut fiber that was well preserved, as well as gravel, being all two with highly siltation.

PVC and ceramic pipes were well preserved, but some deffects have been observed in ceramic pipe installation. All drainage pipes (PVC and ceramic) are non-functional, and presented 30-100% of mineral siltation. Analytical results of trench drainage material and siltation material are shown on Table 3.3.18.

Table 3.3. 18. Analytical results from trench drainage and siltation materials.

	Trench drainage material		Siltation material	
	Mean	Standard deviation	Mean	Standard deviation
pH				
pH water 1:2.5	9.5	0.5	9.4	0.5
pH paste	9.0	0.8	8.5	0.3
Organic matter	0.6	0.2	0.3	0.1
SALINITY				
CEe 1:5 dS m^{-1} at 25°C	0.4	0.2	0.4	0.2
CEe dS m^{-1} at 25°C	3.4	1.7	2.9	1.8
SAR	23.8	17.7	13.9	12.0
Ca^{2+}/Mg^{2+}	2.2	1.0	1.5	0.6
TEXTURE				
Sand (%)	27.4	15.6	13.3	16.0
Silt (%)	50.4	13.1	56.0	14.1
Clay(%)	22.2	5.4	30.7	17.2
θ_{-33Kpa} (%)	29.1	3.6		
$\theta_{-1500Kpa}$ (%)	7.7	0.9		

In PVC pipes the silting material is finer than 2 mm, while in ceramic pipes small gravels appear in the filling material close to joints. In San Juan plot coarser material was also found in ceramic pipe siltations (Herrero *et al*, 1989).

Two soil pits were made in a San Lorenzo experimental plot with PVC pipe and straw envelope and ceramic pipe with gravel envelope. Soil descriptions are found in Appendix 3.3 (4SANLORENZO/1 and 4SANLORENZO/2).

3.3.4.5.1. Processes: translocations of solid material

In San Lorenzo as well as in San Juan, sedimentary structures have been found in the silting material. Also, birefringent clay was found in the drainage pipes and envelopes, which points out the existence of clay iluviation processes inside the drainage pipes.

3.3.4.5.2. Soil technology: silting risk criteria

Uniformity coeficient ($Cu=D_{60}/D_{10}$; being D_x the diameter through which pass the x% weight of the sample) has been used as a silting risk evaluation index for several authors (Lennoz-Gratin, 1987; Dieleman *et al.*, 1984; Willardson *et al.*, 1979), but not in saline conditions. As much as granulometric uniformity increases, Cu decreases and it is supposed to have higher silting risk. Cu critical values varie in different countries are: 2 (France), 4 (USA), 5 (Germany) and, in saline conditions Herrero *et al.*(1989) proposed 5 as a critic value. From data obtained during this study (macro and micromorphological features) an increase in the critic value to 10 is proposed. But caution is recommended in the use of this parameter, taking into account other important soil factors as ESP, clay mineralogy and structural stability.

3.3.4.5.3. Some proposed solutions to avoid siltation

In relation to solutions, a laboratory experiment using soil monoliths was carried out (Porta et al, 1996) in order to determine amendments (gypsum and cement were used) that could improve the drainage system.

The results showed that the cement monoliths had the highest salt exporting efficiency and were the most efficient in the export of sodium, followed by the gypsum columns ones. Gypsum and cement helped in clay flocculation, and with cement amendment larger aggregates were formed, which derived in higher porosity and structural stability and lack of solid translocations under laboratory conditions.

3.3.4.6. Structural stability and soil and water management (Stops 4 and 5)

Sodic soils in the study area have a more complex genesis than the other soils (Rodriguez-Ochoa et al, 1989). An example of sodic soil is found in Callen and San Lorenzo (descriptions 5CALLEN and 4SANLORENZO/1-2; Appendix 3.3).

The ochric epipedon, under rainfed conditions, is usually preserved, has sandy loam texture and its depth is between 2 to 25 cm. The endopedon presents prismatic structure (sometimes columnar) and coatings associated to pores, root channels and aggregate faces. Other features are the presence of friable calcium carbonate nodules, from 5 to 15 mm in diameter, and iron-magnanese nodules (diameter up to 1 mm) that can be seen in thin sections (Sanz et al, 1996).

The structure of the B horizon changes gradually to laminar structure (fine grained laminated material type) which characterizes the C horizon (García-Gonzalez, 1996).

Under rainfed conditions the epipedon does not contain soluble salts ($CE_{1:5} < 0.2$ dS m^{-1} at 25°C) is not sodic (ESP < 2%) and is not alkaline ($pH_{water\ 1:2.5} < 8.7$).

The endopedon and C horizon present high alkalinity levels (pH equal to 10 in some cases) and ESP higher than 15%.

Soil genesis studies must consider the whole picture: the origin of the sandy epipedon, an endopedon with textural coatings and the presence of fine laminated material at the lower part of the soil profile.

Morphoscopic study (scanner electronic microscopy) led us to reject the eolic origin of the sand of the topsoil. The proposed explanation considers a relative sand enrichment by three possible reasons:

- lateral loss of fine material in slope positions (Servat, 1966) or
- eluviation processes or
- absolute enrichment from a more sandy material over the pre-existent which should suppose a lithologic discontinuity through a burying process linked to colluvium.

Textural coatings in the illuvial endopedon have a hue redder than 10YR, which corresponds to textural features of birefringent impure clay in thin sections. ESP in the endopedon is higher than 15% and a Btna horizon "sensu estricto" can be considered. Micromorphological studies confirmed the illuvial process and the soils will be then classified as Typic Natrixeralfs (SSS, 1996).

In the endopedon fine laminated materials have been found in pockets. This is the material found in C horizon and we conclude that the finely laminated material has been the parent material of the upper horizon.

3.3.4.6.1. A comparison of natric vs. other horizons:

Horizons with properties different from these of natric horizons, have been found in the area: soils with finely laminated materials and soils with well-developed structure and heterogeneous textural skins, and must be separated at cartographic level. Table 3.3.19 shows some properties of these materials.

Table 3.3. 19. Main characteristics of sodic materials in subsurface conditions.

Genetic horizon	ESP	SAR	Hydraulic conductivity (10^{-5} m s^{-1})	ECe dS m^{-1} at 25ºC	pH saturated paste	% naturally dispersed clay	Textural classe (USDA)
C	20.3-54.2	16.1-48.3	0.69-8.10	1.35-4.76	8.9-10.0	56.8-87.3	SicL-Sic
Btna	15.3-89.0	10.5-97.7	9.25-16.20	1.55-9.60	8.4-10.3	43.4-74.9	SiL-SicL
Bw	28.7-49.3	33.4-45.5	5.78-13.88	6.15-9.03	9.1-10.1	17.5-48.5	SicL-Sic

A morphological gradation can be defined from these soils materials assuming their origin is the finely laminated materials. Pediality increases from: A-C, to A-Bw-C and A-Btnak-C soils.

This process is associated to translocations of solid material, which give rise to unsorted textural pedofeatures in Bw horizons, and to sorted textural features and birefringence in Btna horizon.

Disorganization of the laminated material by faunal bioturbation or anthropic action make the interpretation of the observed coatings difficult in many cases.

Soils with textural pedofeatures in non-pedologic structured horizons, mainly with very fine lamination inherited from the parent material, can have the analytical requirements for a natric horizon, but skins are associated to the formation of the laminated material and no to soil formation. These soils, which are very unfavourable to plant growth, do not have a natric horizons.

In relation to agricultural use, the common characteristic of these soils are the high alkalinity of the subsurface horizon, but there are differences in relation to infiltration rate, hydraulic conductivity and root penetrability.

Under rainfed conditions soils with laminated materials present a sandy epipedon and as a result a moderately high infiltration rate (1.2-1.44 m day^{-1}). If the laminated material or natric horizon are left at the surface, the infiltration rate decreases considerably (< 0.6 m day^{-1}) which is quite common after levelling.

Hydraulic conductivity down to 100 cm is low in soils with finely laminated materials, due to the horizontal disposition of the material and the non connected porosity.

Soils with Bw or Btnak horizons (Typic Xerofluvents sodic phase or Typic Natrixeralfs) present low or moderate permeability due to the presence of intra and inter-aggregate porosity.

Bulk density in these horizons is high (1.6-1.7 Mg m^{-3}) which implies high compactation. Roots do not penetrate the C horizon, but only the space between aggregates in Bw horizons, and they have less opportunities to explore the soil in Btnak because the structural units are larger (prisms).

Root systems behave differently in the three soil units because of the physical characteristics: strongly limiting in laminated material, moderately limiting in natric endopedons and more favourable in soils with Bw horizon.

For an adequate technology transfer, this different behaviour must be reflected in the taxonomy of the different units shown in the soil map.

3.3.5. Issues related to soil classification

The classification of these soils presents several problems. Some of them are general, others are specific to the classification system used. The main problems found to classify the soils have been:

- Profile disturbance by land levelling
- Soil moisture regime
- Redox status of soils
- Soil temperature regime
- Solid translocations
- Instability of soil structure
- Sodic horizon
- Paralithic contact
- Densic contact
- Fluventic character in fine grained laminated material.
- Stability of levelling material and piping erosion.
- Particle size classes.
- Mineralogy classes.
- Clay activity classes.
- Abrupt textural change

Some of them are discussed below.

3.3.5.1. Profile disturbance by land levelling

In order to apply flood irrigation, land was levelled to a 1-2 ‰ slope. The only references of the old landforms are the aerial photographs before levelling but there is no possibility to contrast in the field such information, which is essential to the cartographic model. The levelling of the land affected different landforms in different ways.

- Lower landforms were moderately affected because there were many erosion forms that were eliminated and also the natural drainage network was altered.

- Residual platforms were slightly affected and only A horizons and in some cases calcic horizons were altered.

- Slopes were strongly affected by land levelling. The A horizons were removed or buried by other materials (lutites, generally) with much worse surface properties (organic matter content, structural stability,...)

In order to classify these soils it is difficult to separate "in situ" from weathered soils and to name the modified horizons.

Furthermore, within-field and betwen-field heterogeneity is high. And although these soils are very disturbed by human activity, they do not fit the definition of Anthrosols in any system.

3.3.5.2. Soil moisture and temperature regimes

Soil moisture regime in the study area is at the borther between Aridic and Xeric (Alberto et al, 1984; Rodriguez-Ochoa et al, 1989).

Using the Jarauta model (1989) the conclusion is that the soil moisture regime is xeric when soil available water (AWHC) is higher than 70 mm.

However a discussion is proposed considering:

- Natural vegetation in the area: some evidences of relict forest with Mediterranean trees and shrubs have been found
- Crop production in rainfed conditions: Historically rainfed agriculture has been based on crops such as cereals (barley and wheat), almonds, olive trees and vineyard
- Other aspects for modelization: potential root depth
north and south aspects
water balance

In the study area, the soil temperature regime is thermic (Rodriguez-Ochoa et al, 1989) close to mesic; from the climatologic study, the boundary to mesic regime is stimated to be at around 400m altitude.

3.3.5.3. Soil redox status

Considering the characteristics of these soils (high pH, high $CaCO_3$ content, poor microbiologic activity,...), there is a poor expression of redoxomorphic features due to the low organic matter availability in the soil, but when organic matter increases those features can be observed.

To evaluate redox conditions we suggest a methodology is based on field morphologies, "in situ" measurements, and tests for redox-condition evaluation proposed by Bartlett and James, (1995)

The studied soils do not fulfil the FAO requirements for anthraquic character associated to paddy soils. Presence of Fe^{+2} (detected with α-α dipiridil) has been found only in a few cases just below the Ap horizon in soils with rice crop.

3.3.5.4. Pedologic structure, aggregation and porosity

The description of soil structure in the field presents many problems (McKeague et al., 1986). Soil classification should consider, at some level, significant aspects of the soil in relation to its functioning and management. Soil structure and porosity plays a key role in the behaviour of these soils. Present systems in use to describe them are poorly suited for soils in the area. There is a need for a better framework to describe soil structure on these soils and integrate them in the soil classification system.

3.3.5.5. Structural instability and translocations of solid materials

Translocations of solid materials are present in most soils of the area, being specially noticeable in soils of the slopes and bottoms.

The evidence is that translocation of particles takes place at different levels and in different horizons. It is clearly related to the structural instability of these soil materials. Such instability is expressed in the formation of surface crusts, (sedimentary, saline and structural), heterogeneous (clay and silt) coatings in plough horizons, textural pedofeatures, silting of drainage networks, gully-piping processes. In field are various negative effects on soil water, salt and gas transference, root development, and crop emergence.

Solid translocations (clay, silt and sand) have been found in soil porosity at different scales (from milimetric pores to centrimetric pipes ....); It is a very active process, acting in short scales of time and with a very significant impact on soil behaviour because its main effect is in the connected porosity of these soils.

Clay accumulations of different origin have been found. Some have developed from illuviation processes, and others from sedimentation processes in instable soils, parent materials, surface crusts and drainage network elements.

Different solid translocation types (Bullock, 1985) have been observed with several degrees of textural sorting, organisation and microscopic birefringence properties which are related to genetic conditions:

- matrix materials
- clay and silt
- clay

These solid translocations with sizes ranging from fine clay to small gravel, throw doubts on classic concepts such as plasma/matrix which are central to soil science studies.

Again, and related to the discussion about soil structure, soil classification should consider this fact through some index of structural instability.

3.3.5.6.-Sodic properties

Presence of sodium in soils is a permanent character. Because of the management problems in sodic soil and the need to unify efforts, some criteria to estimate sodicity are proposed:

A) Chemical conditions: ESP $\geq$ 15 (or SAR $\geq$ 13) during at least one month each year, and 6 out of 10 years.

B) Field conditions (macromorphologic)

B.1) Surface:

- Surface crust presence: Alkaline efflorescences.
- Coatings: Agric character.
- Disperse clay in areas: pH test and soluble salts.
- Surface ponding. Low infiltration rate.
- Aggregate stability (Emerson test; Murphy, 1995)

B.2)Subsurface:

- Solid translocations: natric coatings with high sorting degree.
- pH test and soluble salts.
- Low hydraulic conductivity
- Aggregate stability (Emerson test)

Those parameters could allow to separate different situations and degrees of sodicity conditions allowing different management strategies; further testing of these parameters under different conditions are necessary before implementation.

3.3.5.7. Specific aspects in relation to Soil Taxonomy

- *Redefinition of natric horizon:* seems necessary because it relyes very much in the characteristics of an argilic horizon with specially structural characteristics and sodic condition.

Proposed requirements: It is suggested to redefine the natric horizon taking into account the presence of illuvial materials, not only illuvial clay as it is now; it is demostrated cleary with micromorphological tools which shows more a collapsed structure with movilization of material rather than only clay illuviation. Under this proposal only soil materials showing this pedological process will be considered natric horizon; feature coming from sedimentary processes as fine laminated detritic sediments either in situ either mixed with pedological structured materials, are excluded from the concep of natric horizon.

- Definition of sodic properties

Definition of this character is needed to avoid loss of information when the horizon is near to but does not fulfil the requirements; a sodic character is proposed in agreement to other characters described as vertic.

- New subgroup

When a Natrixeralf soil has a calcic horizon a Calcic Natrixeralf subgroup is proposed (Fitzpatrick and Naidu, 1995).

- Paralithic contact

The application of this concept to the fine grained laminated sediments presents some problems. The behaviour of this material is different in wet or in dry conditions, but in any case roots are not able to penetrate it.

- Densic contact

Soil management in rice fields involves the formation of an impermeable mud layer that can be considered as a densic contact in dry conditions for many soils of the area.

3.3.5.8. World Reference

- Anthropedogenic horizons

Some of the soils affected by land levelling during the transformation of the area to irrigation were deeply disturbed by such operations. But they do not fulfil the veteria for anthropedogenic horizons.

Levelling materials, if anything, fit in the definition of Aric anthropogeomorphic soil material. In the case of soils used for rice production redox features are still extremely incipient and do no meet any of these viteria.

- Salic horizon

The present requirements of electrical conductivity of the saturation extract (15 dS/m and 8 dS/m if the pH is lower or higher than 8.5 respectively) are considered to be too low, and a value closer to around 40 dS/m is suggested. On the other hand, measurement of pH in the saturation extract is not thought to be reliable in this type of soils.

The requirement of 1 percent salt content is also considered no to be useful due to difficulties in its measurement. A requirement of a minimum temporal permanence of saline conditions is considered necessary.

- Aridic Properties and Takyric horizons

Soils in the area have very low organic carbon content and dry conditions which are related to aridic properties. But there are no evidences of aeolian activity, and this aspect excludes them from the definition of Aridic Properties. For the same reason, the fine grained laminated materials, so common in the area, are excluded as Takyric horizons even though they may fulfil the other requirements.

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3.3.6. References

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APPENDIX 3.3.: The site visited (profile description and analytical results)

Profile: 2SANJUAN/1
Location: Saso de San Juan, Sariñena (Huesca).
UTM:30T YM x: 728541
y: 4627765
Altitude: 335 m
Ref. Map: Sheet 325
Parent material
Coarse detritic sediments from Sierra de Alcubierre
Soil temperature regime: thermic
Soil moisture regime: aridic
Geomorphology
Regional landform: Scale: longitude- several km, width- several Hm; Residual platform, general slope 2%.
Local landform: Local slope:< 1%
Erosion: stable

Hydrology
Water table: not reached.
Soil drainage class: Well drained to quickly drained
Vegetation and land use
Irrigated agriculture, wheat; weeds associated :*Brachypodium phoenicoides*, *Cynodon dactilon*, *Phragmites sp.* and almonds in the surroundings.
Soil technology
Irrigated agriculture without drainage, levelling without top-soil preservation
Surface stoniness
stony (Class 2 FAO), 30% (0.2-6 cm) and 10% (6-25 cm).
Rock outcrops: absent
Salinity and alkalinity
Without efflorescences
Cracking: absent
Compaction: absent

Classification: **Xeric Petrocalcid, loamy-skeletal, carbonatic, active, thermic** (SSS 1996).
Petric Calcisol (WRB, 1998)

PROFILE DESCRIPTION

Ap1 0-28 cm
Slightly moist. 10YR 4/4. 16-35% coarse fragments, up to 6 cm in diameter, tabular-subangular unaltered limestones, not-oriented and regularly distributed; fragments of petrocalcic horizon. Primary structure: moderate, medium subangular blocky. Very high to high porosity, connected and distributed at random: 5-10% of interstitial voids from 0.5 to 2 mm, 3-5% of interstitial voids with Ø<0.5 mm, 1% of channels from 2 to 5 mm, 5-10% of planar voids from 0.5 to 2 mm. Loam. Compact, friable. Organic matter: moderately abundant (from 2 to 5%) and well incorporated. Faunal activity: few galleries. Few roots, fine and very fine (Ø<2mm), dead by end cycle, vertically oriented and regularly distributed. Oxidised, well aerated. Very strong reaction to HCl 11%. Clear and smooth boundary due to ploughpan. OCHRIC epipedon.

Ap2 28-47/52 cm
Moist. 10YR 4/4. 36-70% coarse fragments, up to 25 cm in diameter, tabular-subangular unaltered limestones, not-oriented and distributed in strips, fragments of petrocalcic horizon. Primary structure: very weak or weak, fine subangular blocky. Low porosity, connected: 3% of planar voids with Ø<0.5 mm, 1-2% of channels from 0.5 to 2 mm. Silty loam. Compact, friable. Organic matter: little (from 1 to 2%) and well incorporated. Faunal activity: few galleries. Few roots, very fine (Ø<1mm), dead by end cycle, vertically oriented and regularly distributed. Oxidised, well aerated. Very strong reaction to HCl 11%. Abrupt and slightly wavy boundary due to ploughpan. OCHRIC epipedon.

Bwk 47/52-54/60 cm
Slightly moist. 10YR 5/6. 16-35% coarse fragments, up to 6 cm in diameter, tabular-subangular unaltered limestones, not-oriented and regularly distributed. Primary structure: moderate, fine subangular blocky. Moderate porosity: 5% of interstitial voids with Ø<2 mm, 1% of channels from 0.5 to 2 mm, 5% of planar voids with Ø<0.5 mm. Silty loam. Compact, friable. Faunal activity: few galleries. Very few roots, very fine (Ø<1mm), dead by end cycle, vertically oriented and regularly distributed. Oxidised, well aerated. Very strong reaction to HCl 11%. Frequent accumulation of $CaCO_3$, nodules, pseudomycelia and soft powdery lime. Clear and discontinuous boundary. CALCIC endopedon.

Bkm1/Bk 54/60-85/95 cm (cemented horizon with some strips without cementation).
Slightly moist. 2.5YR 7/3; 10YR 6/3. More than 70% coarse fragments in the Bkm1 strip and from 5 to 15% in the Bk, up to 6 cm in diameter, tabular and subrounded unaltered limestones, not-oriented and regularly distributed. Primary structure: very weak and very fine subangular blocky in the Bk and massive in the Bkm1. High connected porosity (Bkm1): 10-15% of planar voids with Ø<2 mm, 1% of channels from 0.5 to 2 mm. High connected porosity (Bk): 10% of interstitial voids with Ø<0.5 mm, 10% of channels from 0.5 to 2 mm, 2% of planar voids with Ø<0.5 mm. Bk is sandy clay loam. Bk is compact and friable, Bkm1 is very compact and very firm. Bkm1 has discontinuous and weak cementations of $CaCO_3$, conglomeratic type. Faunal activity: little, refilled chambers in the Bk. Bk and Bkm1oxidized. Very strong reaction to HCl 11% in Bk and in Bkm1. Generalised and hard accumulations of $CaCO_3$, conglomeratic type (calcareous crust) in Bkm1, and secondary accumulations of $CaCO_3$. in the Bk. Bkm1 boundary is abrupt and slightly wavy. PETROCALCIC endopedon with calcic strips (Bkm1).

Bkm2 85/95-135/+ cm
Slightly moist. 2.5YR 6/3. More than 70% coarse fragments, up to 6 cm in diameter, tabular and subrounded, unaltered limestones, not-oriented and regularly distributed. Primary structure: massive. Compact and extremely firm. Continuos and strongly cemented accumulation of $CaCO_3$, conglomeratic type. Oxidised. Very strong reaction to HCl 11%. Generalised and hard accumulations of $CaCO_3$, conglomeratic type (calcareous crust), and secondary accumulations of $CaCO_3$. PETROCALCIC endopedon.

ANALYTICAL RESULTS PROFILE

Horizon	Depth (cm)	Colour Munsell (moist)	pH (H_2O) 1:2.5	E.C1:5. dS/m 25°C	Organic Matter (%)	Textural class (USDA)
Ap1	0-28	10YR 4/4	8.4	0.22	1.77	Loam
Ap2	28-47/52	10YR 4/4	8.7	0.19	1.51	Loam
Bwk	47/52-54/60	10YR 5/6	8.8	0.23	0.89	Sandy Loam
Bk	54/60-85/95	10YR 6/3	8.6	0.19	1.03	Sandy Loam
Bkm1	54/60-85/95	2.5Y 7/3	8.4	0.22	1.96	Sandy Loam
Bkm2	85/95-135/+	2.5Y 6/3	8.6	0.16	0.37	Sandy Loam

Horizon	Moisture content (%)		Available water (%)	Hydraulic conductivity Ksat. (mm/day)	$CaCO_3$ (%)	CEC/Clay (%)
	-33 kPa	-1500 kPa				
Ap1	19.2	10.4	8.8	696	43.5	0.36
Ap2	18.0	11.2	6.8		43.5	0.45
Bwk	22.4	11.0	11.4		62.1	0.37
Bk	--	--	--		71.0	0.35
Bkm1	--	--	--		78.4	0.73
Bkm2	--	--	--		68.8	0.31

Horizon	Particle size distribution							
	Sand (%)					Silt(%)		Clay(%)
	very coarse	coarse	medium	fine	very fine	coarse	fine	
Ap1	3.1	3.2	4.8	12.2	13.3	19.2	21.3	22.8
Ap2	5.3	3.6	4.5	10.1	13.8	18.8	24.5	19.3
Bwk	11.4	8.8	8.3	11.4	10.7	15.1	21.1	13.2
Bk	14.1	9.6	11.2	14.0	9.2	11.7	17.4	12.8
Bkm1	15.5	10.0	11.3	14.9	7.8	13.1	19.5	7.9
Bkm2	21.9	13.1	11.8	11.4	7.6	11.3	13.9	8.9

Horizon	Particle size distribution without $CaCO_3$								Textural class (USDA)
	Sand (%)					Silt(%)		Clay (%)	
	very coarse	coarse	medium	fine	very fine	coarse	fine		
Ap1	0.2	0.2	1.7	12.5	17.7	26.2	14.9	26.6	Loam
Ap2	0.3	0.2	0.2	10.2	19.0	28.0	19.0	23.1	Loam
Bwk	0.2	0.2	1.1	16.8	3.4	33.1	32.9	12.2	Silt loam
Bk	n.d.	0.2	0.8	14.6	16.1	38.4	12.3	17.6	Silt loam
Bkm1	n.d.	0.2	0.2	10.1	22.2	47.3	13.6	6.3	Silt loam
Bkm2	n.d.	0.3	0.3	4.6	15.3	51.2	13.5	14.7	Silt loam

n.d.: no detected

Horizon	Coarse fragments (%)						
	64-32 mm	32-16 mm	16-8 mm	8-4 mm	4-2 mm	%Coarse fragments	%Fine earth
Ap1	8.3	17.6	14.4	6.3	6.1	52.7	47.3
Ap2	4.3	10.7	11.0	9.7	9.7	45.6	54.4
Bwk	4.3	19.5	6.1	5.4	8.0	43.8	25.2
Bk	17.3	20.2	16.9	8.6	7.4	70.6	29.4
Bkm1	n.d.	12.8	19.3	9.2	9.8	51.1	48.9
Bkm2	5.3	20.9	26.2	15.2	10.9	78.5	21.5

n.d.: no detected

Horizon	STRUCTURAL STABILITY EMERSON'S TEST (MURPHY 1995)	
	Distilled water	Irrigation fresh water E.C.: 0.40; SAR: 1.60
Ap1	4	4
Ap2	4	4
Bwk	4	4
Bk	--	--
Bkm1	4	4
Bkm2	--	--

Horizon	Cation-exchange(cmol(+)/ kg soil)								
		Extractable				Exchangeable			
	CEC	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}
Ap1	8.3	16.94	0.41	0.70	0.32	6.87	0.41	0.70	0.32
Ap2	8.8	20.23	0.12	0.62	0.24	7.82	0.12	0.62	0.24
Bwk	5.4	18.74	0.04	0.38	0.10	4.88	0.04	0.38	0.10
Bk	5.0	20.42	0.01	0.35	0.02	4.62	0.01	0.35	0.02
Bkm1	6.9	26.23	0.10	0.33	0.06	6.41	0.10	0.33	0.06
Bkm2	2.9	17.33	0.02	0.23	n.d.	2.65	0.02	0.23	n.d.

n.d.: no detected

Horizon	Semy-quantitative mineralogy of the clay fraction (Ø<2μm) with decarbonation treatment							
	Phyllosilicates	Quartz	Feldspars	Goethite	Illite	Chlorite	Pyrophyllite	Kaolinite
Ap1	83	6	8	3	74	5	3	1

Profile: 3VERTIENTE
Location: Cantera de las negras, San Juan de Flumen, Sariñena (Huesca).
UTM: 30T YM x: 732222
y: 4628024
Altitude: 295 m
Ref. Map: Sheet 325
Parent material
Fine detritic colluvial sediments.
Soil temperature regime: thermic
Soil moisture regime: Aridic
Geomorphology
Regional landform: Scale: several dam; slightly concave slope general slope 8%.
Local landform: Levelled, local slope:< 1%, aspect 150°SE.
Erosion: Gully-piping erosion, mass movement
Vegetation and land use
Halophilic and nitrohalophilic bushes: *Suaeda Atriplex, Salsola vermiculata, Plantago cornopulus, Inula cripmoigdes.* Agricultural and cattle use is unattended.

Soil technology
Potentially irrigated areas without drainage and with intense levelling.
Surface stoniness
Stony, 50% (0.2-6 cm), and 1% (6-25 cm).
Rock outcrops: absent
Salinity and alkalinity
Without efflorescences
Surface crust: Zone 1: silty sedimentary crust in area next to the top bank, 15-30% of surface affected, 2-5 cm of thickness, weak, porosity with cavities in some lamination phases. Zone 2: In top zones structural disruptive crust, 75% of surface, 1 cm of thickness, slightly hard, porosity vesicular (more pores than zone 1), and in bottom zones sedimentary crust, 25% of surface, 1-10 cm of thickness and liquenic and algal crust.
Hydrology
Water table: not reached.
Soil drainage class: well drained
Cracking: Very fine and shallow (2-3 cm) cracks
Surface structure: structureless, puffing.

Classification: **Xeric Torrifluvent, coarse loamy/ coarse silty, mixed (calcareous), thermic, active** (SSS 1996).
Salic Fluvisol (WRB, 1998)

PROFILE DESCRIPTION

Crust 0-2cm
Dry. Very high porosity, no connected: 5% planar pores with Ø<0.5 mm, 40% vesicular voids with Ø<0.5 mm. Very little organic matter (from 0.2 to 1%) . Few, fine and very fine (Ø<2mm) roots, with horizontal and vertical orientation, alive or dead and regularly distributed. Oxidised. Strong reaction to HCl 11%. No accumulations. Abrupt and smooth boundary.

A 2-40 cm
Dry. 10YR 5/6. 16-35% coarse fragments, up to 2 cm in diameter, tabular and subrounded unaltered limestones, not oriented, with and regularly distributed. Primary structure: apedal, solid. Low porosity and connected: channels from 0.5 to 5 mm, planar voids < 2 mm, vughs and vesicular vughs from 0.5 to 5 mm. Sandy-loam. Very compact, very hard. Not cemented. Very little organic matter (from 0.2 to 1%). Few roots, fine and very fine (Ø<2mm), with horizontal and vertical orientation, alive or dead and regularly distributed. Oxidised. Strong reaction to HCl 11%. Less than 10% of surface affected by silty and silty-clay cutans, associated to pores. No accumulations. Abrupt and smooth boundary. OCHRIC epipedon.

2Ctna 40-65 cm
Dry. 10YR 4/6. 16-35% coarse fragments, up to 2 cm in diameter, tabular and subrounded unaltered limestones, not-oriented, and regularly distributed. Primary structure: apedal, solid. Very low to medium porosity, barely connected: 15% planar voids with Ø <0.5 mm, 15% vesicular voids with Ø <0.5 mm. Sandy-loam. Very compact, very hard. Not cemented. Very little organic matter (from 0.2 to 1%). Few roots, fine and very fine (Ø<2mm), with horizontal and vertical orientation, alive or dead and decreasing with depth. Oxidised. Strong reaction to HCl 11%. Less than 10% of surface affected by silty and silty-clay cutans, associated to pores. No accumulations. Abrupt and irregular boundary. OCHRIC endopedon.

3Ctna/4Ctna 40/65 - 120/135 cm
Dry. 10YR 4/6; 7.5YR 5/6. Less than 1% coarse fragments up to 0.6 cm in diameter, tabular and subrounded unaltered limestones, not-oriented, and regularly distributed. Primary structure: apedal, solid (apedal platy in 4Ctna). Porosity (3Ctna): 5-10% channels with Ø<0.5 mm, less than 1% of channels from 0.5 to 5 mm. Porosity (4Ctna), few connected: 10-15% vesicular voids with Ø<0.5 mm, 3-5% interstitial voids from 0.5 to 2 mm, 1-2% of channels with Ø< 2 mm, 1% of vughs from 0.5 to 2 mm. Sandy-loam. Very compact, very hard. Not cemented. Very little organic matter (from 0.2 to 1%). Very few roots, limited by a very compact horizon. Oxidised. Strong reaction to HCl 11%. Less than 10% of surface affected by silty and silty-clay cutans, associated to pores. No accumulations. Abrupt and irregular boundary. OCHRIC endopedon.

5Ctna 120/135 - 175/+ cm
Dry. 10YR 6/4. 1-5% coarse fragments up to 0.6 cm in diameter, tabular and subrounded unaltered limestones, not-oriented, associated to strips. Primary structure: apedal, platy. Porosity: 3-5% of channels from 0.5 to 2 mm, 3-5% of vughs from 0.5 to 2 mm, 2% of vesicular voids <0.5 mm. Sandy-loam. Very compact, slightly hard. No cemented. Very little organic matter (from 0.2 to 1%). Very few roots, limited by a very compact horizon. Oxidised. Pores, channel type >0.5 mm in diameter and in proportion of 50-60/ 30 cm^2. Reaction to HCl 11% strong. Less than 10% of surface affected by silty and silty-clay cutans, associated to pores. No accumulations. Abrupt and irregular boundary. OCHRIC endopedon.

ANALYTICAL RESULTS PROFILE

Horizon	Depth (cm)	Colour Munsell (moist)	pH (H_2O) 1:2.5	E.C1:5. dS/m 25°C	Organic Matter (%)	Textural class (USDA)
Crust	0-2		8.2	2.61	0.76	Loam
A	2-40	10YR 5/6	9.4	1.02	0.35	Loam
2Ctna	40-65	10YR 6/4	9.7	1.16	0.28	Loam
3Ctna	40/65-120/135	10YR 6/4	10.1	0.99	0.20	Silt loam
4Ctna	40/65-120-135	7.5YR 5/6	9.9	0.85	0.23	Silt loam
5Ctna	120/135-175/+	10YR 6/4	10.1	1.00	0.18	Silt loam

Horizon	Moisture content (%)		Available water (%)	Hydraulic conductivity Ksat.	$CaCO_3$ (%)	CEC cmol(+)/kg	CEC/Clay (%)
	-33 kPa	-1500kPa					
Costa	14.7	5.2	9.5	2.2	31.8	4.5	0.26
A	12.5	5.9	6.6		33.5	4.4	0.27
2Ctna	14.0	5.0	9.0	1.1	32.1	4.5	0.28
3Ctna	21.0	6.0	15.0	1.4	27.7	4.8	0.29
4Ctna	16.7	4.1	12.6	--	33.1	3.2	0.22
5Ctna	--	--	--	--	23.5	4.8	0.24

Horizon	Particle size distribution							
	Sand (%)					Silt(%)		Clay(%)
	very coarse	coarse	medium	fine	very fine	coarse	fine	
Crust	2.1	2.3	3.9	12.9	12.7	21.3	28.2	16.5
A	2.1	1.0	1.5	12.1	13.9	25.0	28.9	15.4
2Ctna	2.8	2.5	3.9	20.4	10.9	19.3	25.4	14.8
3Ctna	0.3	0.8	2.0	6.8	9.6	24.8	39.9	15.8
4Ctna	1.5	1.2	1.6	9.2	15.5	25.2	31.5	14.3
5Ctna	0.9	0.9	0.4	1.9	5.0	27.3	45.6	18.7

Horizon	Particle size distribution without $CaCO_3$								Textural class (USDA)
	Sand (%)					Silt(%)		Clay (%)	
	very coarse	coarse	medium	fine	very fine	coarse	fine		
Crust	n.d.	0.5	2.0	10.2	13.6	17.6	32.1	23.9	Loam
A	n.d.	0.2	1.2	9.5	13.9	17.9	33.0	24.3	Silt loam
2Ctna	0.2	0.2	0.6	5.3	8.2	14.3	44.1	27.1	Silty clay loam
3Ctna	0.2	0.5	1.4	3.4	4.0	7.4	58.0	25.0	Silt loam
4Ctna	0.2	0.2	0.7	3.3	3.8	5.7	57.1	28.9	Silty clay loam
5Ctna	0.3	0.6	2.4	5.3	3.9	5.9	57.8	23.8	Silt loam

n.d.: no detected

Horizon	Coarse fragments (%)						
	64-32 mm	32-16 mm	16-8 mm	8-4 mm	4-2 mm	%Coarse fragments	%Fine earth
Crust	n.d.	1.8	10.8	7.4	6.7	26.8	73.2
A	n.d.	2.5	6.6	4.4	3.0	16.6	83.4
2Ctna	n.d.	0.5	1.8	4.4	4.2	11.0	89.0
3Ctna	n.d.	n.d.	n.d.	0.2	0.1	0.4	99.6
4Ctna	n.d.	n.d.	3.7	3.6	2.8	10.1	89.9
5Ctna	n.d.	n.d.	0.1	0.04	0.04	0.2	99.8

n.d.: no detected

Horizon	STRUCTURAL STABILITY EMERSON'S TEST (MURPHY 1995)	
	Distilled water	Irrigation fresh water E.C.: 0.40; SAR: 1.60
Crust	2(1)	2(1) (zones 3 in crust fragments)
A	2(2)	2(1)
2Ctna	1	2(2)
3Ctna	1	2(2)
4Ctna	1	2(2)
5Ctna	1	2(3)

Horizon	S. M.	pH_p	Saturated soil paste extract								
	%		E.C.$_e$ dS/m 25 °C	pH_e	Soluble anions (meq/l)						
					Cl^-	SO_4^{2-}	NO_3^-	CO_3^{2-}	HCO_3^-	PO_4^{3-}	Σ Anion
Crust	31.7	7.4	40.13	7.9	302.7	35.2	1.0	n.d.	12.2	n.d.	351.1
A	29.8	8.3	18.00	8.4	137.7	26.2	0.2	n.d.	13.6	n.d.	177.7
2Ctna	28.8	8.2	17.34	8.4	129.8	22.0	n.d.	n.d.	11.4	n.d.	163.2
3Ctna	29.0	9.3	14.35	8.9	126.9	29.9	n.d.	0.8	4.8	n.d.	162.4
4Ctna	28.1	8.7	16.71	8.6	124.1	26.0	n.d.	0.8	17.2	n.d.	168.1
5Ctna	30.8	9.3	11.58	8.9	80.2	20.5	n.d.	2.0	16.8	n.d.	119.5

n.d.: no detected

Horizon	Soluble cations (meq/l)						
	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	Σ Cation	Ca^{2+}/Mg^{2+}	SAR
Costra	16.4	14.2	337.3	3.2	0.4	371.5	1.1	86.26
A	8.1	2.7	180.6	4.5	0.5	196.4	3.0	77.72
2Ctna	5.6	3.1	170.7	0.5	n.d.	179.9	1.8	81.84
3Ctna	4.6	1.3	153.0	5.5	1.7	166.1	3.5	89.08
4Ctna	3.7	1.6	149.2	1.9	0.3	156.7	2.3	91.65
5Ctna	3.3	1.2	106.1	2.5	0.3	113.4	2.7	70.73

n.d.: no detected

Profile: IV-S.LORENZO/1
Location: San Lorenzo (Huesca). Drainage experimental plot.
UTM: 30T YM x: 735925
y: 4639819
Altitude: 292 m
Ref. Map: Sheet 325
Parent material
Fine laminated detritic sediments
Soil temperature regime: thermic
Soil moisture regime: xeric
Geomorphology
Regional landform: Bottom valley, general slope 3%
Local landform: Local bottom with levelling and with slope lower than 1%.
Erosion: some problems of erosion by gully-piping in banks.
Hydrology
Water table: 115 cm..
Soil drainage class: moderated well drained
Vegetation and land use
Agriculture: *Medicago sp. Trifolium sp., Lotus* sp, *Platago coronopus, Puccnellia* sp, *Atriplex hastata, Espergularia* sp.
Soil technology
Flood irrigation. PVC drainage non functional (silted).
Surface stoniness: absent
Rock outcrops: absent

Classification: **Xeric Torriorthent, fine silty, carbonatic, active, thermic, shallow** (SSS, 1996)
Calcaric Fluvisol (Sodic) (WRB, 1998)

PROFILE DESCRIPTION

A (crust) 0-5/6 cm
Slightly moist. 10YR 5/6. Less than 1% coarse fragments, up to 0.2 cm in diameter, tabular-subrounded unaltered limestones, not-oriented and regularly distributed. Primary structure: moderate medium platy. Porosity: vesicular voids in the first 15 mm with Ø<1mm, less than 5% of perpendiculars voids in the first 2 mm, 20% vesicular voids and no connected, 25% vughs no connected, 10% planar with Ø<2 mm. Silty loam. Moderately compact, very friable. Organic matter: very little(from 0.2 to 1%). Few roots, fine and very fine (Ø<2mm). Oxidised . Very strong reaction to HCl 11%. No reaction to DIPY-1. No accumulations. Abrupt and smooth boundary. OCHRIC epipedon.

Ap1 5/6-30/34 cm
Slightly moist. 10YR 5/6. Less than 1% coarse fragments, up to 0.2 cm in diameter, tabular-subrounded unaltered limestones, not-oriented and regularly distributed. Primary structure: coarse subangular blocky and apedal cloddy. Porosity: less than 5% horizontal voids, 1% verticals channels from 0.5 to 2 mm, 2% vughs with Ø <2mm distributed regularly, less than 1% planar voids with Ø <0.5mm. Silty loam. Compact, friable. Organic matter: very little (from 0.2 to 1%). Few roots, fine and very fine (Ø<2mm). Oxidised. Very strong reaction to HCl 11%. No reaction to DIPY-1. Less than 10% of surface affected by silty-clay cutans and silty-matrix cutans. No accumulations. Clear and smooth boundary due to ploughpan. OCHRIC epipedon.

C 30/34-115/+ cm
Moist. 2.5YR 6/4. Few mottles, extremely small, irregular shape, associated to pores and roots, due to oxidation process. Moist. Primary structure: very weak, thick, platy. Porosity: less than 1% channels with Ø<1mm. Compact, friable. Few roots, very fine (Ø<1mm), limited by paralithic contact. Oxidised. Very strong reaction to HCl 11%. No reaction to DIPY-1. Less than 10% of surface affected by silty-clay cutans. No accumulations.

Sandy layer 115 cm

ANALYTICAL RESULTS PROFILE

Horizon	Depth (cm)	Colour Munsell (moist)	pH (H_2O) 1:2.5	E.C1:5. dS/m 25°C	Organic Matter (%)	Textural class (USDA)
A (crust)	0-5/6	10YR5/6	10.0	1.66	0.78	CL
Ap	5/6-30/34	10YR5/6	10.3	0.66	0.48	L
C	30/34-115/+	2.5Y6/4	10.2	0.58	0.58	SL

Particle size distribution USDA			Moisture content (%)		Available water (%)	Hydraulic conductivity Ksat. (mm/day)	$CaCO_3$ (%)
Sand (%)	Silt (%)	Clay(%)	-33 kPa	-1500 kPa			
31.67	38.84	29.49	20.7	8.8	11.9	90	28.9
29.04	48.50	22.46	23.1	9.8	13.3	100	31.3
0.78	75.25	23.97	31.8	7.0	24.8		27.1

Horizon	STRUCTURAL STABILITY EMERSON'S TEST (MURPHY 1995) Distilled water	Irrigation fresh water E.C.: 0.40; SAR: 1.60
A (crust)	2(1)	2(1)
Ap	2(3)	2(1)
C	1	2(2)
Sandy layer	1	2(1)

Horizon	S. M.	pH_p	Saturated paste extract						
			E.C.$_e$	Soluble anions (meq/l)					
	%		dS/m 25 °C	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	Σ Anion	Cl^-/SO_4^{2-}
A (crust)	35.3	9.9	17.80	82.3	91.8	2.1	9.2	185.4	0.90
Ap	47.6	10.2	4.12	12.5	13.8	5.0	12.0	43.3	0.90
C	38.7	10.0	2.29	9.9	7.8	1.0	9.0	27.7	1.27

Horizon	Soluble cations (meq/l)						
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Σ Cation	Ca^{2+}/Mg^{2+}	SAR
A (crust)	3.6	2.8	177.6	1.9	185.8	1.30	99.6
Ap	2.0	1.1	41.7	1.0	45.7	1.87	33.8
C	2.4	0.3	21.9	0.5	25.1	8.50	19.0

Horizon	Semi-quantitative mineralogy of the clay fraction (Ø<2μm) with decarbonation treatment							
	Phyllosilicates	Quartz	Feldspars	Goethite	Illite	Chlorite	Pyrophyllite	Kaolinite
Ap	84	9	6	1	78	3	2	1
C	80	15	4	tr	72	4	3	1

tr: traces

	Semy-quantitative mineralogy of the clay fraction (Ø<2μm) with decarbonation treatment							
	Phyllosilicates	Quartz	Feldspars	Goethite	Illite	Chlorite	Pyrophyllite	Kaolinite
Gravel envelope siltation	79	18	3	tr	74	3	2	tr
Drainage pipe siltation	79	21	5	n.d.	76	2	1	tr

tr: traces; n.d.: no detected

4 SL /1: DESCRIPTION OF DRAINAGE TRENCH MATERIAL

No coarse fragments. Primary structure: weak, moderate subangular blocky. Macroporosity: moderate, vugh, policoncave. Bulk density: 1.75 g/cm^3. Silty loam. Generalised coatings, associated to clod faces, with colour (H) 7.5YR6/6 - 2.5YR6/6. Little gypsum, some residues from dilution and reprecipitation. No mottles. No asettlement between walls and ditch.

Depth (cm)	pH 1:2.5	E.C. 1:5 dS/m 25^a	O.M. (%)	$CaCO_3$ (%)	Moisture content (%)		Particle size distribution USDA			Textural class USDA
					-33 kPa	-1500 kPa	Sand(%)	Silt(%)	Clay(%)	
77-95	9.7	0.71	---	22.3	25.98	7.85	1.53	67.85	30.62	silty clay loam

Chemical and physical characterisation

S.M. (%)	pHp	SATURATED SOIL PASTE EXTRACT						
			Soluble anions					
		E.C.e dS/m 25^a	Cl^- (meq/l)	SO_4^{2-} (meq/l)	CO_3^{2-} (meq/l)	HCO_3^- (meq/l)	Σanions (meq/l)	Cl^-/SO_4^{2-}
39.5	10.5	4.2	11.22	2.34	3.2	6.8	44.56	0.49

Soluble anions in drainage trench material

SATURATED SOIL PASTE EXTRACT						
Soluble cations						
Na^+ (meq/l)	K^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	Σcations (meq/l)	Ca^+/Mg^{2+}	SAR
38.5	----	0.65	1.10	40.25	1.69	32.1

Soluble cations in drainage trench material

DESCRIPTION OF DRAIN AND ENVELOPE SILTATION MATERIAL

Siltation macromorphology

Drain type: PVC. Envelope: esparto. Structure: platy. Silt. Transversal and longitudinal silted surface profile: smooth and continuous. Drain functionality: unfunctional. 100% section silted.

Envelope macromorphlogy

Drain type: PVC, 44 mm in diameter. Envelope: esparto. Material not preserved. No retention of fine material. No coarse gypsum elements.

Type (cm)	pH 1:2.5	E.C. 1:5 dS/m 25ª	O.M. (%)	Particle size distribution USDA			Textural class USDA
				Sand (%)	Silt(%)	Clay(%)	
PVC	8.7	0.25	0.10	2.30	81.92	15.78	Silty loam

Chemical characterisation siltation material

S.M. (%)	pHs	SATURATED SOIL PASTE EXTRACT						
			Soluble anions					
		E.C.e dS/m 25ª	Cl^- (meq/l)	SO_4^{2-} (meq/l)	CO_3^{2-} (meq/l)	HCO_3^- (meq/l)	Σanions (meq/l)	Cl^-/SO_4^{2-}
46.2	8.3	1.53	5.45	7.59	1.0	2.66	17.7	0.71

Soluble anions in siltation material

SATURATED SOIL PASTE EXTRACT						
Soluble cations						
Na^+ (meq/l)	K^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	Σcations (meq/l)	Ca^+/Mg^{2+}	SAR
6.95	2.10	3.95	3.17	16.17	1.87	3.7

Soluble cations in siltation material

Profile: IV-S.LORENZO/2
Location: San Lorenzo de Flumen (Huesca). Drainage experimental plot.
UTM: 30T YM x: 735925
y: 4639819
Altitude: 292 m
Ref. Map: Sheet 325
Parent material
Fine detritic sediments. Holocene
Soil temperature regime: thermic
Soil moisture regime: xeric
Geomorphology
Regional landform: San Lorenzo Flumen depression. Slope 1%
Local landform: Bottom, slope 1%.

Erosion: some problems of erosion by gully-piping in banks.

Hydrology
Water table: not reached.
Soil drainage class: moderated well drained
Vegetation and land use
Agriculture: *Medicago sp.* Subexploted, 5000 kg/ha, limiting factor salinity-sodicity.
Soil technology
Irrigation by flood, with ineffective drainage because of salts excess. Levelling without topsoil preservation.
Experimental IRYDA drainage plot (1975)
Surface stoniness: absent
Rock outcrops: absent

Classification: **Typic Natrixeralf fine, mixed (calcareous), termic.** SSS (1975,1994)
Salic Solonetz (WRB, 1998)

PROFILE DESCRIPTION

Ap1na 0-12 cm
Slightly moist. 10YR 5/8. Less than 1% coarse fragments, up to 2 cm in diameter, subrounded spheroids, not-oriented limestones and regularly distributed. Primary structure: weak, coarse and subangular blocky. Loamy. Compact, friable. Organic matter: very little (from 0.2 to 1%). Roots (diameter<10 mm), fine and very fine (Ø<2mm), vertical, regular distribution and dead. Oxidised. Strong reaction to HCl 11%, strong to $BaCl_2$ (5%) and strong to $AgNo_3$ (5%), positive reaction to fenoftaleine. Clear and smooth boundary. OCHRIC epipedon.

Ap2nad 12-33 cm
Slightly moist. 10YR 7/8. Less than 1% coarse fragments, up to 2 cm in diameter, subrounded spheroids, not-oriented limestones and regularly distributed. Primary structure: weak, coarse and subangular blocky. Silty clay loam. Compact, firm. Organic matter: very little (from 0.2 to 1%). Very few roots, fine and very fine (Ø<2mm), vertical, regular distribution, alive or dead, limited by compact horizon. Oxidised. Clear and smooth boundary. OCHRIC epipedon.

Cna (fine grained laminated sediments) 33-58 cm
Slightly moist. 2.5YR 6/8. Primary structure: very weak, thin and platy. Loam. Compact, firm. Roots (diameter<10 mm) fine and very fine (Ø<2mm), vertical, regular distribution, alive or dead. Oxidised. Few matrix coating, associated to pores and channel roots. Abrupt and smooth boundary.

2Btnakn 58-92 cm
Slightly moist. 7.5YR 5/6. 16-35% coarse fragments, up to 6 cm in diameter, subrounded spheroids, not-oriented limestones and regular distribution. Primary structure: moderate, coarse prismatic. Secondary structure: weak, fine subangular blocky. Silty clay. Compact, firm. Faunal activity: little (<1%) filling cavities. Very few roots, fine (1-2 mm Ø), vertical, regular distribution, alive or dead. Very few mottles (<1%) due to oxidation, extremely fine (<1 mm), irregular, associated to faces structural elements. Oxidised. Frequent (distance 10-30 cm) cracks, verticals, continuos and stuffed. Frequent coatings (10-50% surface affected), associated to pores and root channels and to structural elements. Frequent accumulations (2-20% volume), friable nodules of $CaCO_3$, medium size (5-15 mm), regular distribution, soft. Gradual and smooth boundary. NATRIC-CALCIC endopedon.

2Bwna 92-120 cm
Slightly moist. 7.5 YR 6/6. Primary structure: Very weak, medium and subangular blocky. Silty clay. Compact, firm. Many mottles(20-50%) due to oxidation, extremely fine (<1 mm), irregular, associated to faces structural elements. Oxidised. Abrupt and smooth boundary.

3Cr (Lutite) 120-140/+ cm
Slightly moist. 5Y 6/6. Silty clay. Compact, firm. Oxidised.

ANALYTICAL RESULTS PROFILE

Horizon	Depth (cm)	Colour Munsell (moist)	pH (H_2O) 1:2.5	E.C.1:5. dS/m 25°C	Organic Matter (%)	Textural class (USDA)
Ap1na	0-12	10YR 5/8	10	0.70	0.86	L
Ap2nad	12-33	10YR 7/8	10.1	1.10	0.54	Scl
Cna	33-58	2.5Y 6/8	10.4	0.82	0.52	Cl
2Btnakn	58-92	7.5YR 5/6	10.4	0.85	0.38	Sc
2Bwna	92-120	7.5YR 6/6	10.4	0.93	0.31	Sc
3Cr	120-140/+	5Y 6/6	10.5	0.65	0.35	Sc

Particle size distribution USDA			Moisture content (%)		Available water (%)	Hydraulic conductivity Ksat. (mm/day)	$CaCO_3$ (%)
Sand (%)	Silt (%)	Clay (%)	-33 kPa	-1500 kPa			
30.24	46.22	23.54	28.2	9.1	19.1		26.7
1.33	68.05	30.62	30.6	8.7	21.9	70	25.2
28.15	44.59	27.26	32.6	7.9	24.7		22.8
4.44	53.36	42.20	30.2	12.4	17.8		20.7
4.64	53.22	42.14	29.0	12.9	16.1	100	20.0
4.91	44.38	50.71	32.4	19.4	13.0		19.3

Horizon	S. M.	pH_p	Saturated paste extract						
			$E.C._e$	Soluble anions (meq/l)					
	%		dS/m 25 °C	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	Σ Anion	Cl^-/SO_4^{2-}
Ap1na	40.9	9.2	3.92	14.8	13.3	2.6	9.8	40.5	1.11
Ap2nad	33.3	10.0	9.20	62.9	25.8	1.0	6.4	96.0	2.44
Cna	33.5	10.6	5.65	23.7	23.2	3.0	10.2	60.1	1.02
2Btnakn	34.4	10.5	3.51	9.0	16.5	2.5	8.5	36.5	0.55
2Bwna	32.5	10.2	4.40	11.7	18.9	3.0	6.5	40.1	0.62
3Cr	45.7	10.2	4.48	10.8	20.6	1.7	4.8	37.8	0.53

Horizon	Soluble cations (meq/l)						
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Σ Cation	Ca^{2+}/Mg^{2+}	SAR
Ap1na	2.0	0.7	37.6	0.5	40.8	2.91	32.6
Ap2nad	1.3	1.3	90.5	1.0	94.1	1.00	78.2
Cna	1.2	3.4	60.9	1.5	66.9	0.35	40.3
2Btnakn	2.4	0.3	34.4	1.3	38.4	8.50	29.8
2Bwna	1.6	0.7	46.3	0.0	48.6	2.29	43.2
3Cr	1.4	0.9	45.8	0.0	48.1	1.50	43.2

Horizon	Cation-exchange (cmol(+)/ kg soil)												
		Extractable				Soluble				Exchangeable			
	CEC	Ca^{+2}	Mg^{+2}	Na^+	K^+	Ca^{+2}	Mg^{+2}	Na^+	K^+	Ca^{+2}	Mg^{+2}	Na^+	K^+
Ap1na	12.5	3.3	0.4	6.9	0.1	0.1	0.0	1.5	0.0	6.6	0.4	5.4	0.1
Ap2nad	10.6	2.8	0.4	10.2	0.1	0.0	0.0	3.0	0.0	3.0	0.3	7.2	0.1
Cna	8.2	2.1	0.1	7.7	0.1	0.0	0.1	2.0	0.1	2.5	0.0	5.7	0.0
2Btnakn	11.2	2.2	0.2	7.4	0.1	0.1	0.0	1.2	0.0	4.8	0.2	6.2	0.1
2Bwna	13.8	2.0	0.1	11.2	0.1	0.1	0.0	1.5	0.0	3.9	0.1	9.7	0.1
3Cr	20.2	1.9	0.2	14.4	0.2	0.1	0.0	2.1	0.0	7.6	0.2	12.3	0.2

Horizon	ESP (1)	ESP (2)	ESP (SAR)	CEC/Clay (%)
Ap1na	55.3	43.2	31.9	0.53
Ap2nad	96.1	67.9	53.3	0.35
Cna	94.0	69.5	36.8	0.30
2Btnakn	65.9	55.4	29.9	0.26
2Bwna	81.4	70.3	38.4	0.33
3Cr	71.1	60.9	38.4	0.40

ESP(1): Calculated from extractable cations.
ESP(2): Calculated using Bower (1954) methodology.
ESP(SAR): Calculated from SAR.

4 SL /2: DESCRIPTION OF DRAINAGE TRENCH MATERIAL

1-5% coarse fragments up to 2 cm in diameter, tabular-subrounded limestones and regularly distributed. Material aspect: clods and lutite fragments mixed. Primary structure: weak, coarse subangular blocky. Macroporosity: low. Bulk density: 1.88 g/cm^3. Silty clay loam. Sandy coatings in the contact between trench and material in situ. No gypsum. Frequent mottles due to oxidation, fine and rounded, with colour (H) 7.5YR4/6. No asettlement between walls and ditch.

Depth (cm)	pH 1:2.5	E.C. 1:5 [a]	O.M.	$CaCO_3$	Moisture content (%)		Particle size distribution USDA			Textural class
		dS/m 25	(%)	(%)	-33 kPa	-1500 kPa	Sand(%)	Silt(%)	Clay(%)	USDA
45-68	10.2	0.60	0.54	25.4	25.12	8.99	4.15	65.67	30.18	Clay loam

Chemical and physical characterisation

S.M. (%)	pH_p	SATURATED SOIL PASTE EXTRACT						
			Soluble anions					
		E.C.e dS/m 25[a]	Cl^- (meq/l)	SO_4^{2-} (meq/l)	CO_3^{2-} (meq/l)	HCO_3^- (meq/l)	Σanions (meq/l)	Cl^-/SO_4^{2-}
33.8	10.2	5.2	20.81	20.31	3.8	15.1	60.63	1.02

Soluble anions in drainage trench material

SATURATED SOIL PASTE EXTRACT						
Soluble cations						
Na^+ (meq/l)	K^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	Σcations (meq/l)	Ca^+/Mg^{2+}	SAR
57.45	2.56	1.25	0.75	62.01	1.66	62.00

Soluble anions in drainage trench material

DESCRIPTION OF DRAIN AND ENVELOPE SILTATION MATERIAL

Siltation macromorphology

Drain type: ceramic. Envelope: gravel. Structure: platy. Silty clay loam. Transversal and longitudinal silted surface profile: smooth and continuous. Drain functionality: unfunctional. 80-90% section silted and 100% silted in joint.

Envelope macromorphlogy

Drain type: ceramic, 80 mm in diameter. Envelope: gravel, well preserved. High accumulation of fine material increasing in the vertical direction to the drain and coatings 90% of grains. No coarse gypsum elements.

Type (cm)	pH 1:2.5	E.C. 1:5 dS/m 25ª	O.M. (%)	Particle size distribution USDA			Textural class USDA
				Sand (%)	Silt(%)	Clay(%)	
ceramic	10.2	0.58	0.07	31.42	54.13	14.45	silty loam

Chemical characterisation siltation material

S.M. (%)	pHs	SATURATED SOIL PASTE EXTRACT						
			Soluble anions					
		E.C.e dS/m 25ª	Cl^- (meq/l)	SO_4^{2-} (meq/l)	CO_3^{2-} (meq/l)	HCO_3^- (meq/l)	Σanions (meq/l)	Cl^-/SO_4^{2-}
45.0	9.3	4.2	14.9	22.35	2.66	7.66	47.57	0.66

Soluble anions in siltation material

SATURATED SOIL PASTE EXTRACT						
Soluble cations						
Na^+ (meq/l)	K^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	Σcations (meq/l)	Ca^+/Mg^{2+}	SAR
39.56	1.38	3.57	2.13	46.64	1.67	23.4

Soluble cations in siltation material

Profile: V CALLEN
Location: Callén (Huesca)
UTM: 30T YM x: 717809
y: 4650575
Altitude: 330 m
Ref. Map: Sheet 324
Parent material
Fine laminated detritic sediments. Holocene
Soil temperature regime: thermic
Soil moisture regime: xeric
Geomorphology
Regional landform:
Semi-endorreic depression of Callen, slope <2%
Local landform: Local bottom with levelling and with slope < 0.1%.

Hydrology
Water table: 230 m.
Soil drainage class: moderated well drained
Vegetation and land use
Agriculture: Rice, unattended.
Halophils and higrophils bushes: *Suaeda vera*, *Phragmites sp.*
Soil technology
Irrigation by flooded without drainage Levelling without" capaceo". Mackerel and urban residues amendments. SIA-DGA testing of tolerating prairies to salinity-sodicity (1988).
Surface stoniness: absent
Rock outcrops: absent

Classification: **Typic Xerofluvent fine silty, mixed (calcareous), thermic.** SSS (1996)
Calcaric Fluvisol (sodic) (WRB, 1998)

PROFILE DESCRIPTION

Ap1zna 0-7 cm
Dry. 10YR 6/8. 1-5% coarse fragments, up to 2 cm in diameter, subrounded spheroids, not-oriented limestones and regularly distributed. Primary structure: weak, coarse subangular blocky. Porosity with low connectivity: few fine channels, frequent medium channels and few planar voids. Clay loam. Compact. Organic matter: little (from 1 to 2%). Biological activity: few channels worms(<1%). Human activity: many mackerel and urbane residues. Very few roots, horizontal, and dead, limited by salinity-sodicity and compacity. Oxidised. Strong reaction to HCl 11%, strong to $BaCl_2$ (5%) and strong to $AgNo_3$ (5%), positive reaction to fenoftaleina (in profile and puddles). Frequent matrix coatings (10-50% surface affected), associated to pores and root channels and to structural elements. Frequent accumulations (2-20% volume), humic material and soluble salts efflorescences in surface. Inferior boundary abrupt and smooth. OCHRIC epipedon.

Ap2nad 7-15/20 cm
Slightly moist. 10YR 6/8. 1-5% coarse fragments, up to 6 cm in diameter, subrounded spheroids, not-oriented limestones and regularly distributed. Primary structure: weak, moderate, subangular blocky. Porosity with low connectivity (<10%), associated to apedal material: many fine channels, frequent medium channels and few coarse channels. Clay loam. Very compact, firm. Organic matter: little (from 0.2 to 1%). Biological activity: Few worm channels. Human activity: many mackerel and urban residues. Few matrix coatings (<10% surface affected), associated to pores. Oxidised. Abrupt and smooth boundary. OCHRIC epipedon.

Bwna 15/20-40/44 cm
Slightly moist. 10YR 4/6. No coarse fragments. Primary structure: weak, prismatic, coarse. Secondary structure: weak, moderate, subangular blocky. At 30% of surface, laminar, fine and weak structure, locally distributed. Silty clay loam. Compact, firm. Biological activity: frequent earthly gasteropod shells. Frequent silty and clay coatings (10-50% surface affected), on aggregates, pores and root channels vertical faces. Few matrix coatings (<10% surface affected) associated to prism faces. Gradual and wavy boundary.

B/C 40/44-75
Slightly moist. 10YR 5/6. No coarse fragments. Primary structure: weak, moderate, prismatic. At 25-50% of surface, weak, very thin platy structure. Silty clay loam. Very compact, friable. Biological activity: few earthly gasteropod shells. Frequent silty and clay coatings (10-50% surface affected), on aggregates, pores and root channels vertical faces. Abrupt and smooth boundary.

2Bwna 75-90
Slightly moist. 10YR 5/6. No coarse fragments. Primary structure: very weak, coarse subangular blocky. Sandy loam. Loose, friable. Biological activity: very few and very big filling channels, frequent channels. Frequent silty and clay coatings (10-50% surface affected), associated to sand grains. Abrupt and smooth boundary.

3Cna 90-120
Moist. 10YR 6/8. No coarse fragments. Primary structure: strong. Silty loam. Loose, friable. Few matrix coatings (<10% surface affected), associated to pores.

ANALYTICAL RESULTS PROFILE

Horizon	Depth (cm)	Colour Munsell (moist)	pH (H_2O) 1:2.5	E.C1:5. dS/m 25°C	Organic Matter (%)	$CaCO_3$ (%)	Hydraulic conductivity Ksat.(mm/day)
Ap1zna	0-5	10YR 6/8	10.6	2.99	1.20	42.5	4.9
Ap2nad	7-15	10YR 6/8	10.5	1.18	1.30	43.1	
Bwna	15-40	10YR 4/6	10.5	2.12	0.87	23.0	
B/C	40-75	10YR 5/6	10.5	0.88	0.60	22.9	5.7-20.6
2Bwna	75-90	10YR 5/6	10.4	0.48	0.27	24.8	--
3Cna	90-120	10YR 6/8	10.5	0.56	0.36	26.5	--
auger-hole	140-160		10.3	0.64	0.44	27.9	--

Horizon	Particle size distribution (%)			Textural class (USDA)
	Sand (%)	Silt (%)	Clay (%)	
Ap1zna	22.3	48.20	29.50	Cl
Ap2nad	20.2	51.90	27.90	Cl
Bwna	10.40	61.70	27.90	Scl
B/C	4.50	57.20	38.30	Scl
2Bwna	58.32	23.34	18.34	Sal
3Cna	19.01	64.92	16.07	Sl
auger-hole	--	--	--	--

Horizon	S.M. %	pH_p	Saturated paste extract						
			E.C.e dS/m 25 °C	Soluble anions (meq/l)					
				Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	Σ Anion	Cl^-/SO_4^{2-}
Ap1zna	42.9	10.2	26.99	106.5	148.3	34.0	12.7	301.5	0.72
Ap2nad	47.4	10.1	8.95	19.3	41.9	17.2	28.3	106.7	0.46
Bwna	43.8	10.1	6.15	14.5	32.0	17.3	11.3	75.1	0.45
B/C	41.5	10.4	4.40	18.8	10.9	23.3	15.1	68.1	1.72
2Bwna	39.2	10.4	4.20	8.7	6.4	15.2	10.0	40.3	1.36
3Cna	33.3	10.3	4.85	12.1	10.7	13.1	11.2	47.0	1.13

Horizon	Soluble cations (meq/l)						
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Σ Cation	Ca^{2+}/Mg^{2+}	SAR
Ap1zna	4.1	2.3	305.9	–	312.3	1.78	171.0
Ap2nad	3.8	1.7	100.4	–	105.9	2.24	60.5
Bwna	3.5	2.0	64.7	–	70.2	1.75	39.0
B/C	2.6	1.5	59.2	–	63.3	1.73	41.4
2Bwna	1.8	1.6	32.6	–	36.0	1.13	25.0
3Cna	0.8	1.5	44.0	–	46.3	0.53	41.0

Horizon	Cation-exchange (cmol(+)/ Kg soil)												
		Extractables				Soluble				Exchangeable			
	CEC	Ca^{+2}	Mg^{+2}	Na^+	K^+	Ca^{+2}	Mg^{+2}	Na^+	K^+	Ca^{+2}	Mg^{+2}	Na^+	K^+
Ap1naz	11.0	4.1	0.7	18.6	0.8	0.3	0.2	13.1	0.1	4.4	0.5	5.4	0.7
Bwna	11.0	4.8	0.5	8.3	0.4	0.2	0.1	2.8	0.0	6.7	0.4	5.5	0.4
B/C	17.8	4.5	0.6	8.2	0.2	0.2	0.1	2.5	0.0	11.7	0.6	5.7	0.2
2Bwna	9.2	5.1	0.3	5.8	0.2	0.1	0.1	1.3	0.0	5.5	0.3	4.5	0.2
3Cna	6.9	1.9	0.3	5.6	0.0	0.1	0.1	1.5	0.0	1.4	0.2	4.1	0.0

Horizon	ESP (1)	ESP (2)	ESP(SAR)	CEC/Clay (%)
Ap1zna	168.2	49.3	71.5	0.37
Bwna	75.0	49.5	46.8	0.39
B/C	46.1	32.1	36.0	0.46
2Bwna	62.2	48.2	37.4	0.50
3Cna	80.7	59.0	26.3	0.43

ESP(1): Calculated from extractable cations.
ESP(2): Calculated using Bower (1954) methodology.
ESP(SAR): Calculated from SAR.

Horizon	Semy-quantitative mineralogy of the clay fraction (∅<2μm) with decarbonation treatment							
	Phyllosilicates	Quartz	Feldspars	Goethite	Illite	Chlorite	Pyrophyllite	Kaolinite
Apzna	82	14	4	tr	81	1	tr	tr
B/C	80	12	7	1	79	1	n.d.	n.d.

tr: traces; n.d.: no detected