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3.2.The contrast of the drylands versus the old and new irrigated districts in Quinto [1]

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[1] Part of this chapter is extracted from the book: O. Artieda (1996) **Génesis y distribución de suelos en un medio semiárido. Quinto (Zaragoza).** Ministerio de Agricultura Pesca y Alimentación. Madrid. 222 pp + map.

3.2.The contrast of the drylands versus the old and new irrigated districts in Quinto

3.2.1. Introduction

The Ebro Valley is carved in Miocene strata of sandstone, marls, limestone and gyprock. Some of these materials contain soluble salts. The average annual water deficit (reference evapotranspiration minus precipitation) at the Zaragoza observatory is around 1000 mm, greater than some classical 'arid observatories' around the world (Herrero and Snyder, 1996). The climate and the soil parental materials produce desert landscapes that support peculiar ecosystems and need an adapted agriculture.

The soils to be visited are in the municipality of Quinto, in the right bank of the Ebro river, downstream of Zaragoza (Fig. 3.2.1). Barley is the only feasible crop in the unirrigated lands, but yield is often low or nil, and in most years is not harvested but grazed by sheeps. Only a scarce and elderly population remains because of the lack of stable income. People perceive these lands as marginal, and thus waste disposal or quarrying of alabaster, clay and gravel have been easily accepted. Protection of the arid ecosystems has been recently promoted by some private and public organizations.

Irrigated agriculture has supported human life in the central Ebro Valley since ancient times. Maize, alfalfa, wheat, barley, peas, sunflower, onions, fruit trees are some of the common crops that grow in the irrigated lands. Now, the conflict between agricultural and urban uses of water has produced strong criticisms against irrigation.

Quinto contains an old surface-irrigated district in the lower terrace of the Ebro river. A new irrigated area of around 2500 ha started eleven years ago by pumping water 130 meters of vertical elevation from the Ebro river. Sprinkler and drip irrigation allow good productions not only in gypseous soils, but also in some enclaves of saline soils where subsurface drainage pipes were installed.

The trip will show some of the representative soils of Quinto and their relationships with the landscape and land use.

This Chapter is based on previous works carried out in the Department of Soils and Irrigation of the Agri-Research Service of the Government of Aragon, as part of several research projects funded by the Agriculture Ministry of Spain.

The consent of Octavio Artieda to use in this Chapter many materials from his book (Artieda, 1996), as well as his advice and collaboration are here acknowledged.

3.2.2. Location of the studied area

The studied area is the municipality of Quinto located in Aragon, Northeastern Spain, 60 km southeast of Zaragoza. Elevation ranges from 150 m to 312 m.

The Ebro river borders Quinto in the Northeast, and is the only permanent river in the studied area. The Lopin barranco borders Quinto in the South; other small barrancos are Valdecenicera and Valdecara, that now collect effluents from the new irrigated lands.

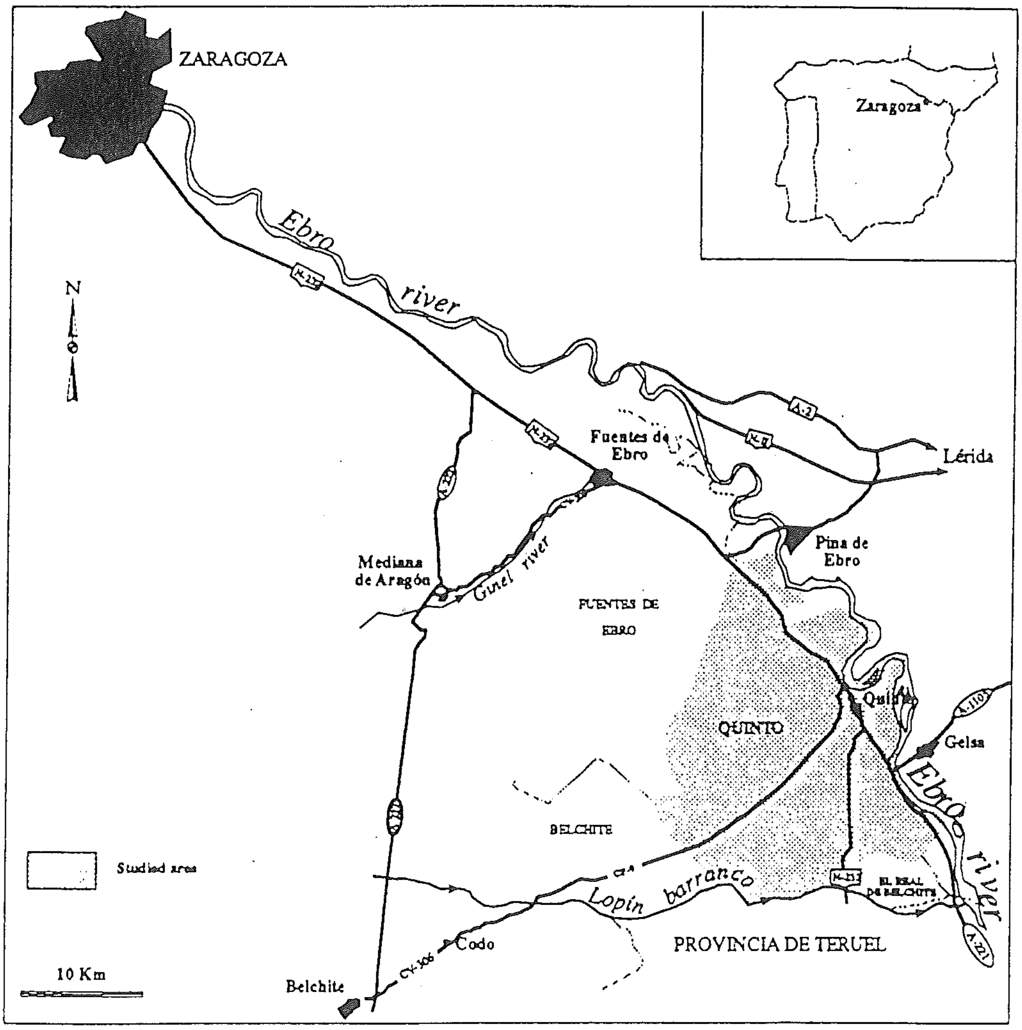

Figure 3.2.1. Location of the studied area.

3.2.3. Climate and waters

3.2.3.1. *Atmospheric climate*

Table 3.2.1 shows the monthly and yearly averages of precipitation, temperature and reference evapotranspiration (ET_0) calculated by Faci and Martínez-Cob (1991) from data of the Zaragoza-Aeropuerto observatory. The elevation of this observatory is 240m, and the distance from Quinto is 60 km. The observatory of Belchite is closer to the study area, but its records are not continuous. This weather station recorded an absolute maximum temperature of 44°C in the 30 July 1983, and absolute minimum temperatures of about -7°C in several days of January 1985.

Table 3.2.1. Average weather data (1970-1989) of the Zaragoza-Aeropuerto observatory.

Month	**P (mm)**	**T max. (°C)**	**T min. (°C)**	**T. med. (°C)**	**ET_0 (mm)**
January	23,5	10,2	2,5	6,4	24
February	21,3	12,8	3,6	8,2	45
March	22,4	15,7	4,8	10,3	83
April	32,5	18,3	7,2	12,8	112
May	40,8	22,3	10,6	16,5	145
June	39,7	27,3	14,6	21,0	172
July	16,8	31,0	17,4	24,2	188
August	18,1	30,3	17,3	23,8	161
September	22,8	26,8	14,5	20,7	115
October	26,1	20,6	9,9	15,3	88
November	31,7	14,2	5,7	10,0	39
December	23,9	10,3	3,3	6,8	22
Year	319,6	19,98	9,3	14,7	1194

3.2.3.2. *Agroclimatology*

The temperature regime is megathermic after the Thornthwaite (1948) system, and the humidity regime is arid. With the same system, but using other set of observatory records, the climate of Zaragoza was classified by Liso and Ascaso (1969) as semiarid mesothermic without water excess during all the year.

After the Papadakis (1961) system, winter is 'Avena fresh', and summer is 'Oryza', with a Continental thermic regime. The water regime is Mediterranean, and the climatic regime is continental temperate Mediterranean.

3.2.3.3. *Edaphic climate*

In the Ebro valley the atmospheric climate recorded by weather stations has to be used to estimate the soil climate, required by S.S.S. (1975) at the highest taxonomic level. After the revision for Spain by Herrero and Porta (1991), and according to Alberto *et al.* (1984), the soils of Quinto have an aridic moisture regime and a mesic temperature regime. However, the climate of the soils in the old irrigated lands in the low Ebro terrace needs additional discussion. The criteria of S.S.S. (1975) were not conceived for soils with millennia of anthropization including natural vegetation substitution and irrigation. In the last two centuries these actions intensified by the control of river flow by huge reservoirs, the works against floods along the lower terrace, gravel quarrying, and others. A compromise is to consider moisture regime aridic, bordering xeric or ustic. One more time, the moisture regime has to be supposed, but discussion is open in the lacking of field data.

3.2.3.4. *Climate and geomorphic processes*

After the morphogenetic classification of Wilson (1968) of the climate-process systems, and using the yearly averages of precipitation and temperature, runoff is the main agent. Wind erosion, mass movements, and mechanical weathering act moderately. Chemical weathering is moderate to minimal. The landforms that can be predicted are glacis, fans or dejection cones, and angular slopes with coarse detritic materials.

These processes are zonal and quite theoretical, and are modified by extrazonal factors, like the base level of the Ebro river. In the same way, the strong rain and temperature contrasts, and the short and intense rains, favourish the runoff and surface weathering. Moreover, gyprock and limestone suffer karstification.

3.2.3.5. *Hydrology*

The Ebro river is the only permanent stream in Quinto; where the yearly average electrical conductivity (EC) is 1.2 dS/m at 25°C (Aragüés and Alberto, 1983), increasing from 1961 to 1990 at a rate of 8.5 mg L^{-1} by year (Quílez, 1998). After Herrero and Bercero (1991), the water pumped in Quinto in 1988 had an estimated average EC of 1.35 dS m^{-1}, with calcium and sulfate as dominant ions. The level of the main aquifer, located in the recent Ebro alluvium, is related to the amount of the river flow. Climate precludes the local recharge of the aquifers.

Around 2500 ha are under sprinkling from 1989, and some 50 ha are under drip irrigation (Herrero and Bercero, 1991). The lutites caused water ponding in some sites, but it disappeared after the installation of subsurface drainage pipes and the opening of several ditches.

Limestones transmit water throughout their diaclase net, whereas lutites act as impervious producing subsurface aquifers without deep drainage. Lateral flow can be seen in the escarpments, where seepage is frequent. Effluents are saturated in calcium and sulfate, and have high magnesium contents.

3.2.4. Geology

3.2.4.1. *Regional evolution during the Quaternary*

At the end of the Tertiary, the Ebro basin opened into the Mediterranean, probably in relation with the Messinian revolution. After the development in the Middle Miocene of the "Fundamental erosion surface" in the East-central Iberian Cordillera (Simón, 1982), a distensive step produced the relative uplift of the Cordillera against the Ebro depression. Sedimentary materials were accumulated in the depression because of the denudation of the borders.

In the Central Ebro Valley, the infillings of the vales, the deposits in the regular slopes, the glacis, and the terraces are Pliocene and Quaternary. Zuidam (1976) reported an accumulative step in the outskirts of Zaragoza from 500 a.C. to 100 a.C., corresponding to the infilling of vales. Gutiérrez and Peña (1992) recognized in Mediana de Aragón (Fig. 3.2.1) two infillings of vales. The older was made before or during the Iron Age, and continues after the Iberian and Roman years. The datation of the youngest infilling is unclear. In the Huerva valley, close to Quinto area, Peña *et al.* (1996) detect infillings of the Upper Pleistocene-Lower Holocene, and a more recent infilling from 6000 years ago until post-roman years, with recent gradations and incisions.

3.2.4.2. *The geology of Quinto*

3.2.4.2.1. Lithostratigraphy

The main geologic materials of Quinto are Tertiary lutites, limestones and gypsum; and Pliocene and Quaternary deposits of fluvial terraces, slope deposit, infilling of vales, etc.

The Tertiary materials are in horizontal or subhorizontal strata, and belong to the tectosedimentary units T4 (Oligocene-Miocene) and T5 (Lower Miocene: Agenian-Middle Aragonian), according to Luzón (1994). The survey by Artieda (1993) shows seven Tertiary lithological units (Table 3.2.2. and Figure 3.2.2.). The dominant rocks in these units and the correspondence with the units of Quirantes (1978) are displayed in the Table 3.2.2.

Table 3.2.2. Correspondence between the Lithostratigraphic Units defined by Quirantes (1978), and the Lithological Units established by Artieda (1993) in Quinto.

Lithostratigraphic Units (Quirantes, 1978)	**Lithological Units (Artieda, 1993)**	**Dominant rocks**
Sástago Limestones (Alcubierre Formation)	EL REAL	Gypsiferous-Calcareous.
	LOPIN	Lutitic. Lutitic-Calcareous-Gypsiferous.
¿ ?		
Codo Member (Longares Formation)	PURBURELL	Lutitic.
	ESQUILZO	Lutitic.
	ATALAYA	Lutitic.
	ARBOLEDA	Lutitic-Marls.
	BONASTRE	Lutitic-Gypsiferous.

The distribution of the Lithological Units of Quinto is shown in Figure 3.2.2, produced from the lithological map at scale 1:25000 (Artieda, 1993).

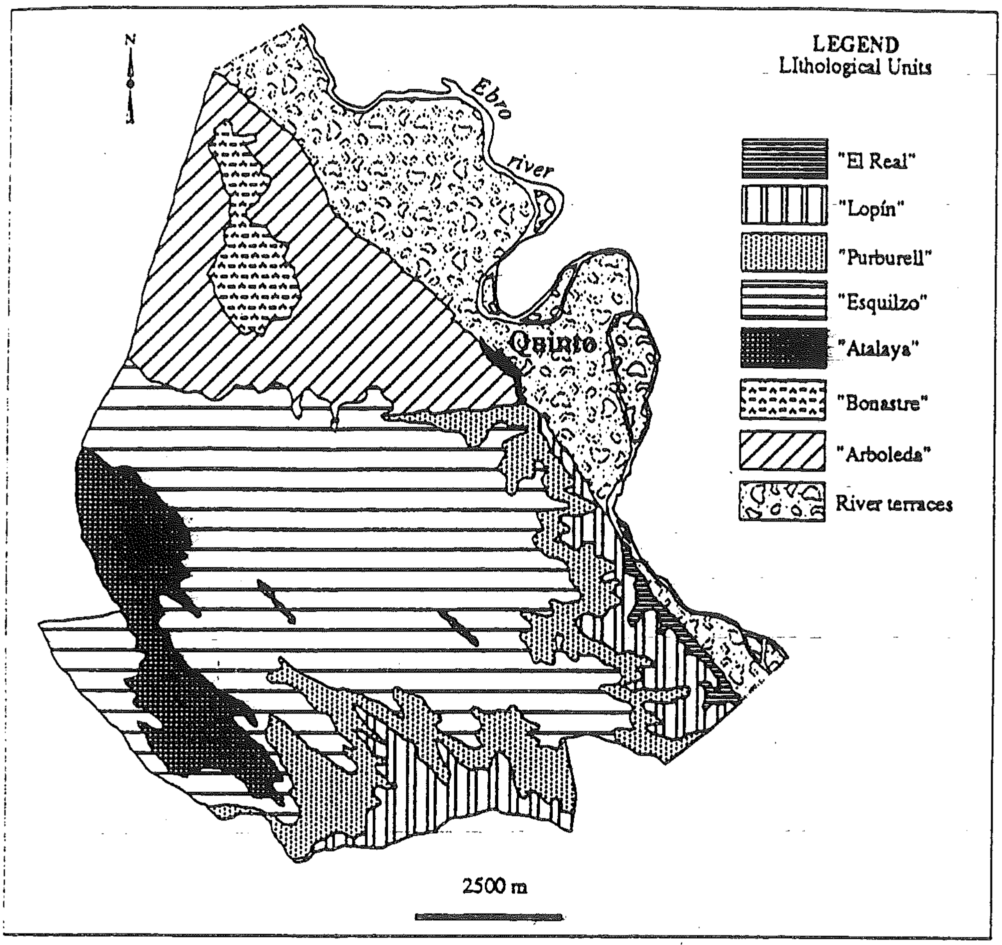

Figure 3.2.2. Sketch map of the Lithological Units established in Quinto by Artieda (1993).

3.2.4.2.2. Petrology

The main Tertiary materials of Quinto are lutites with intercalations of limestone, gypsum, and some arenitic paleochannel. Their complex spatial distribution is typical in the succession of facies in playa-lake environments. The following paragraphs give the morphologic, petrographic and compositional characteristics of these rocks in Quinto.

a) Gypsum.

Gypsum occurs as: (i) continuous levels of centimetric depth interbedded with lutites, (ii) banks of metric depth, (iii) centimetric nodules dispersed inside the lutites, and (iv) fibrous gypsum filling cracks. The lateral extent of these layers ranges from hectometric to kilometric.

The typical structures are algal laminated and nodular. The nodules can be isolated between lutites, or coalesce in chickenwire or in palisade. The nodules range from millimetric to decimetric.

Naked eye, main textures are saccharoidal and microcrystalline; both can coexist in the same layer or in the same sample. Artieda (1993) showed that the main textural types are: (i) porphyroblastic gypsum; (ii) alabastrine gypsum with its three components non-uniform extinction crystals, microcrystalline gypsum, and idiomorphic gypsum; and (iii) fibrous gypsum.

Other sulfates that occur in Quinto are celestite and anhydrite. They are always minority and occurring in relation with gypsum.

b) Limestones

Limestones have ochre, brown, grey or whitish colour, and are laminated and massive, in tabular strata or in lenses of less than 30 cm thick. When the strata occur isolated between lutites, their extent is hectometric; these strata also occur as banks up to 4 m thick, with strata separated by bedding planes or by thin lutite and marl layers. The extent of these banks can be kilometric.

c) Lutites

The lutites of Quinto are included in the Sur series of Pinilla and Alonso (1969), characterized by the abundance of mica and illite, and the scarcity of halloysite.

Lutites, both argillites and limolites, occur in packets from centimeters to meters thick, red or brown, and in some cases green or violet. Lutites are massive, or show bedding of different colours. From the study under X rays of several samples, a 58% (seven samples) have smectites or interstratified illite-smectite, with illite and chlorite as ubiquist. Dolomite appears in the 90% of the samples.

d) Arenites

Some works in close areas (Riba *et al.*, 1967; Quirantes and Martínez, 1967-68; Birnbaum, 1976) refer the occurrence of detrital rocks forming paleochannels or horizontal layers, composed of grains of varied composition (quartz, feldspar, calcite, dolomite) cemented by calcite or gypsum.

Rock bodies with channel shape appear in Quinto showing sedimentary structures like cross and parallel lamination. These bodies, with hectometric length and up to 1 m depth, appear intercalated between lutites and are of detrital origin. In the field they look as a calcareous arenite of middle-fine grain, ochre to grey, compact in fresh cut and brittle after exposure. The petrographic study shows (Artieda *et al.*, 1995) that the main component is replacement dolomite, without matrix. The texture of these bodies is due to the homogeneous size of the dolomite crystals and thus they are not sedimentological sands.

3.2.4.2.3. Geomorphology

The aerial photograms of 1956-57, 1977, and 1990 allowed to verify the changes in many landforms due to earth moving, lands consolidation, irrigation works, waste disposal, quarries, etc. After verification in the field, a geomorphic map at scale 1:25000 was drawn. According to the classical genetic criteria, the mapped forms are ordered in four groups: I structural forms, II accumulation forms, III erosion forms, IV other forms, and V anthropic forms.

I. Structural forms

a) Platforms

An outstanding tabular form appears South of Quinto village. This form is considered a platform in the sense of Twidale (1971). Its surface is around 35 km^2, and the maximum length is 10 km. Its elevation ranges from 200 to 258 m in Fortín, and has a general inclination towards NW of less than one degree, similar to other platforms in the Ebro like La Muela and La Plana cited by Zuidam (1976).

This tabular form is determined by a limestone packet of 2 m depth at the top of this surface. With more detail, this morphologic unit has other superimposed elements like depressions, flat bottomed valleys, and some barrancos with lineal incision and with a centrifuge trend. The South and Northeast borders of this platforms are small cornices or escarpments produced by the lithological contrast and the differential erosion of barranco Lopín and Ebro river. The west end has several structural steps in gyprocks, that could be considered as a small platform. However, their intense dissection by flat bottomed valleys, and the depressions and other accidents superimposed on the gyprock levels faint the general form.

b) Mesas

The term mesa will be applied to those tabular forms smaller than platforms, and delimited all around by a more or less developed escarpment (Figure 3.2.3).

The mesas of Quinto are topped by limestone or gyprock. These forms do not correspond to the buttes of Fairbridge (1968) and Twidale (1971) because of their elongated plant, with the maximum diameter greater than the minimun one and also greater than their elevation on the subjacent plane.

The most outstanding mesas are Loma de Esquilzo, and Cornero (Stop 1 of the excursion), whose limestone tops are at 262 and 266 m elevation, respectively. Both have an elongated plan, with the longer axis at 140°N.

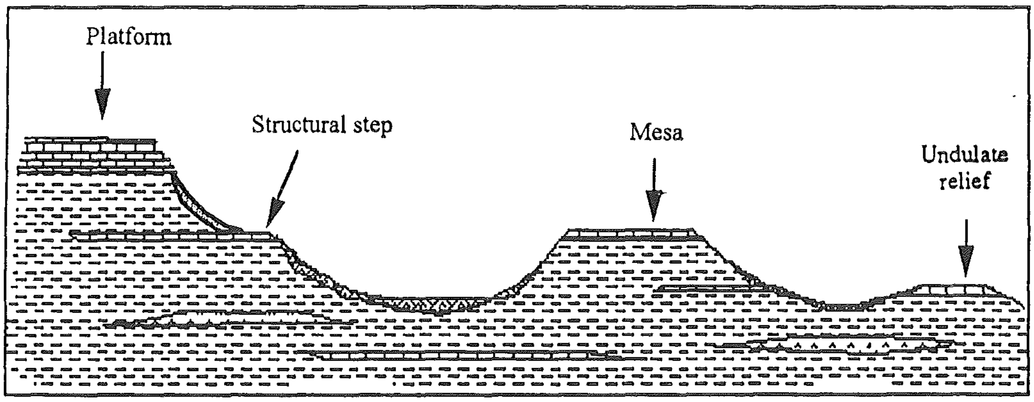

Figure 3.2.3. Evolution of the platform producing limestone mesas and undulate reliefs.

Other limestone mesas appear in the southern area of Quinto. These forms are separated from the platform by flat bottomed valleys. In some cases, the local inclination of the limestone (> 1°) produces small forms qualifying as cuestas after the criteria of Viers (1973).

Mesas culminated by gyprock occur in the west border of Quinto. Their profile is smoother than the mesas in limestone.

c) Undulate reliefs

The topographical relief of these forms is small (< 20 m), and the morphologies are quite varied depending on the kind of culminant materials, limestone or gyprock. In detail, these undulate reliefs (Figure 3.2.3) have a culminant plane in gradual continuity with bare hillslopes, with a small inclination, modelled on an alternance of gyprock and lutites. These forms are separated one from the other by small valleys with rounded transversal profile. All these features make an undulate general landscape.

d) Conic hills

Are structural reliefs with a conic shape produced by the degradation of mesas. In Quinto they are commonly culminated by limestone or gyprock.

e) Erosive plains in lutites

Are flat surfaces developed on lutitic formations. Their surfaces show smooth erosive modelling, mainly ephemeral gullies with incision smaller than 1 m.

II. Accumulation forms

a) Fluvial Complex of the Ebro

Ebro river in Quinto flows from WNW to ESE, with an alluvial plain passing from 5.7 km width in the North to 1 km width in the South. Figure 3.2.4 shows the relative disposition of the several terrace levels, from the highest to the present Ebro river level.

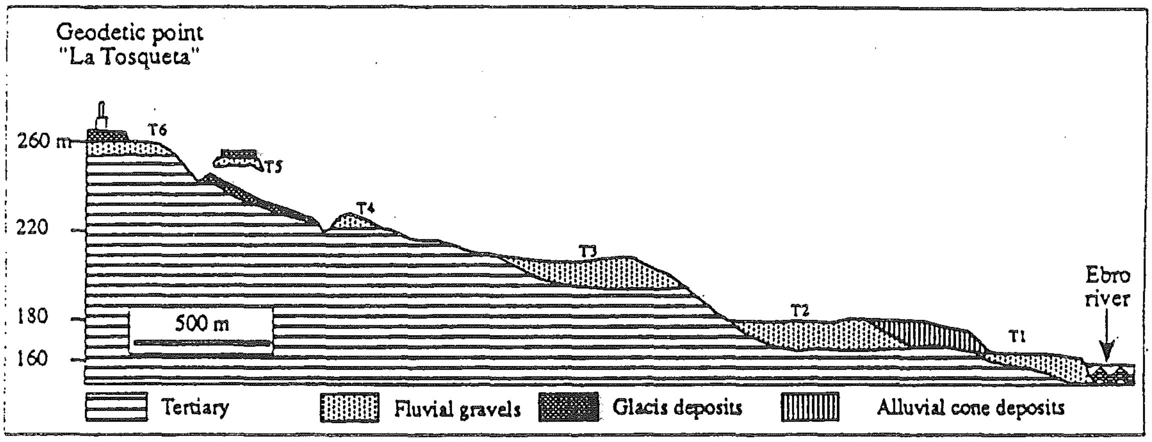

Figure 3.2.4. Sketch of the disposition of the terraces of the fluviatile complex of the Ebro.

The delimitation of the terrace levels of the Fluvial Complex of the Ebro is difficult because of the natural and manmade superimposed modelling. The terraces have been cultivated, and in many cases strongly disturbed. The gravel and sand quarrying has destroyed some outcrops, as it can be seen in aerial photographs of 1956.

The main components of the terraces are gravels and boulders of limestone, granitoids, and red sandstones. The deposits can lack internal ordering or have cross-bedding or planar-bedding. Other common features are the wedge levels, sandy or silty, ochre-greenish, cross-laminated and parallel-laminated. Iron and manganese patinas are frequent in the clasts, as well as the gypsum and carbonate accumulations.

The six levels of Ebro terraces that were found are grouped in stream terraces and old terraces. The stream terrace is the T1 of Figure 3.2.4, with a relative elevation of 2-3 m above the river. Cutoff meanders are frequent and denote the Ebro trend to migrate towards the North; central and lateral bars can also be seen. The other five levels are the old terraces. The materials occurring on these levels are interpreted as coming from an old glacis-slope whose source area was the older terrace levels; charcoal is frequent in the contacts of these deposits. The connection between the different levels is progressive, by means of a glacis-hillslope, without a distinct escarpment. Julián and Chueca (1991) reviewed the proposed datations for the Ebro terraces. After the application of the chronological sequence proposed by these authors, the Quinto terraces of the Ebro river have the following datation:

Holocene		T1	Stream terraces
Pleistocene	Upper Middle Low	T2 T3 and T4 T5 and T6	Old terraces

b) Fluvial Complex of Valdecenicera

The barranco of Valdecenicera carves clay materials. Its left bank is abrupt, with structural steps in gyprock connected with the stream terrace by means of regular hillslopes and glacis. Valdecenicera is now eroding in Quinto a kind of lutitic materials that can be considered either as Tertiary lutites with pedogenesis in situ, or as alluvial lutitic deposits, or as glacis deposits. This indefinition is produced by the clay composition of the Tertiary material carved, by the occurrence of clayed glacis both upstream and in the two sides. The limits for this alluvial level are tentative because of the above reasons.

This alluvial level is made by red and laminated clays, with frequent charcoal fragments. This level is incised, and in some sites shows a distinct escarpment 1 m high.

c) Regular hillslopes

The term regular is here used for steep hillslopes having some detritical coverage. The regularization is often incomplete in Quinto, with the upper stretch bare and vertical, and the lower stretch regularized by a detrital cover. The lower stretch is rectilinear connecting throughout a concave stretch with a glacis or with a flat bottomed valley (Figure 3.2.5). Some covers are thin, but many hillslopes are completely covered by detritics as a result of the several accumulative steps during the Quaternary. The dissection of these slopes by linear incision produces triangular facets whose identification is easy in the field but difficult in aerial photograms.

d) Subactual glacis

Most of the glacis of Quinto belong to the face slope glacis established by Zuidam (1976) in a close area. These levels start from structural reliefs in limestone or gyprock and connect in their lower part with a val, where deposits coming from the opposite direction converge with other glacis. The delimitation is difficult when the base level of glacis are clayed plains, because of the similar colour and the horizontallity in the terminal areas (Figure 3.2.5).

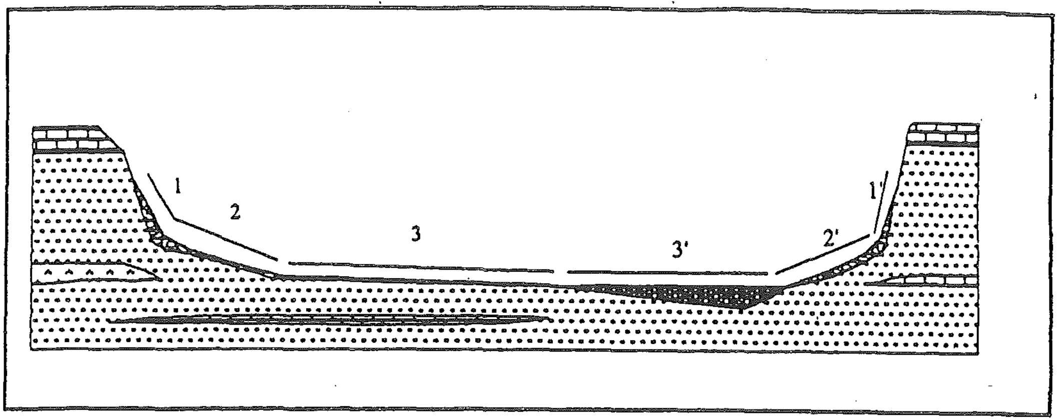

Figure 3.2.5. Outline of the regular hillslopes. Rectilinear stretch (1 and 1'); concave stretch (2 and 2') connecting in its distal part with a glacis (3) or with a flat bottomed valley (3').

e) Slope-glacis

The upper part of this compound form is a hillslope totally regularized by a thin cover, that continues without break of slope in an actual glacis of similar lithology.

These forms occur around the old terraces of the Ebro, that are the source area for a deposit of polygenic clasts included in a loamy matrix. In some sites the coverage of the Tertiary materials is incomplete, producing small undulate reliefs separated by flat bottomed valleys.

Some terrace outcrops have a coverage of polygenic and gyprock clasts. These deposits have metric extent, and are interpreted as remnants of a glacis level whose source was in the older terraces. In the map these deposits are named as 'Disconnected glacis deposits'.

f) Alluvial cones

These forms occur in the outlets of the linear incised barrancos that flow into Ebro, Valdecenicera, and Lopín. The greater alluvial cones are in the North, up to 700 m length and 2 km width; southern cones are shorter and steeper. The alluvial cones in the North and Southeast of Quinto lay directly on the stream terrace of the Ebro, and in same cases several cones are superposed. This fact can indicate dissolution of the underlying material or subsidence by lithostatic pressure on the unconsolidated fluvial deposit.

The original fan shape of these forms is faint by railway, roads, acequias, and agricultural levelling.

g) Vales

The aragonese word "val" (plural: vales), is also used in geomorphology for a typical landscape feature in the central Ebro valley. The vales are the result of the filling of V-shaped valleys. These infillings can have a break of slope with the limiting hillslopes and produce a flat bottomed valley, or not have such a break, producing a cradle valley. Cradle profiles are the most frequent in the heads of the vales or by convergence of two regular hillslopes or two glacis.

Flat bottoms are more common when the lateral slopes that limit the val are bare. The term val is used either for flat bottomed and for cradle valleys.

These infillings have frequent linear incisions with transversal U profile of sheer walls, and a longitudinal profile with an abrupt escarpment in the head. The aragonese name "tollo" is broadly used for these incisions in the geomorphological descriptions. The tollos in Quinto often are 2m deep.

The vales of Quinto are quite rectilinear contrasting against the meander pattern in close areas. This fact is related to the small length, < 4 km. Their width is variable but in general is < 100 m. The borders of the vales are distinct, excepted some vales in the North end of the platform.

Up to three infilling stages have been reported by several authors in the Ebro Valley, but in Quinto only one stage has been observed. Some authors (Llamas, 1962, Torras and Riba, 1967-68) supposed an fluvial-eolic origin for the infilling, but Zuidam (1976) discarded wind as a relevant filling factor.

III. Erosion forms

a) Barrancos with linear incision

Many barrancos of second and third order have a marked V transversal profile, and appear on hillslopes and glacis. They can be associated to an actual erosive stage.

b) Gullies

Badlands produced by gullies are developed around the barranco of Valdecara affecting both distal areas of glacis and the stream terrace. These gullies have only 1 to 1.5 m deep and the crest are rounded. In the surface appear decimetric or centimetric rills with semispheric interrills, that remember the columnar structure typical of sodic soils. Similar features were reported by Finalyson *et al.* (1987) as domed crusts.

c) Bare hillslopes

In these hillslopes the Tertiary is outcropping, or the detritic or weathering cover is very thin. The bare hillslopes on lutites are plough if the slope is < 30°, but the difference of colours related to stratification can be seen. The bare hillslopes on lutites with gyprock and some thin limestone strata produces slopes > 30°.

When the outcropping rocks are gypsum, the hillslopes show greyish colours associated to the surface weathering of gyprock that produces specific morphologies named aljezones by Artieda (1993). Weak non hierarchical incisions are frequent on these hillslopes.

IV. Other forms

Depressions

Both open and close depressions appear in Quinto, with distinct or diffuse limits. Several hypothesis for their formation have been proposed (Mensua and Ibáñez, 1975; Zuidam, 1976), including the dissolution of subsurface gypsum. The gypsum karsts in the Ebro valley has been studied by Gutiérrez et al., 1985; Benito and Gutiérrez, 1987; Pérez and Lanzarote, 1988, among others.

Depressions in Quinto are elongated, and when they are open could also be considered as vales with diffuse limits and small slope. They appear in the platform or in its contact with the glacis. They also appear in flat surfaces on gyprock. Most depressions are connected with the fluvial net, and their origin seems linked to fluvial processes, except those depressions on gyprock.

V. Anthropic forms

The comparison of aerial photograms of 1956 versus 1990 shows heavy changes produced by gypsum, clay and gravel quarries and by agriculture. The quarries stand out because of the talus and the debris piles. In the last years waste disposal from industries has increased covering some barrancos and steep slopes.

Agriculture has impacted most of the lands: changes in plot design, earth moving and land levelling, irrigation and drainage works, and others have been intensive and widespread in the last twenty years.

3.2.4.2.4. Tectonics and neotectonics

The tectonical deformations in Quinto are negligible, as shown by the general disposition of the strata. Normal faults were observed in some few sites, with a general direction E-W and N-S, but their vertical displacements are < 0.5 m. Other general deformations in Quinto are not clearly tectonics, and can be attributed to the increase of volume due to the passage of anhydrite to gypsum.

The diaclases in the limestones are subvertical and the cracks of the same family are from centimeters to decimeters apart. The relationship between diaclases and the geomorphic features is not clear, probably due to the variability throughout the same lithological column (Arlegui, 1992), verified in Quinto by Artieda (1993). Some agreement between diaclases and landforms can be seen only in some sites, like Esquilzo.

No relevant deformations in Quaternary materials were observed.

3.2.5. Soils

3.2.5.1. *Introduction*

Soil genesis and soil-landscape relationships have been established by studying 65 soil pits and many field observations, grouped by areas with similar morphological and lithological characteristics. Several genetic models for different soils are presented in section 3.2.5.3. The classification of the soils up to the subgroup level according to Soil Taxonomy (SSS, 1994) can be found in the section 3.2.5.4.

Methodological aspects of this study are shown in the Annex together with the list of used genetic horizons; also some proposed genetic horizons will appear in the text (between brackets).

3.2.5.2. *Soil-landscape relationships*

Knowledge of relationships between geomorphology and soils is a useful tool for soil mapping in a given area. As stated by Buol *et al.* (1983), such relations use to be tight for soils in humid areas and when underlying sediments are homogeneous; however in arid or semiarid areas with heterogeneous rocks, the relationship is sometimes not so clear.

3.2.5.2.1. Homogeneous Units

We have subdivided Quinto in *Homogeneous Units* with similar features (morphology, climate, lithology, processes, soils, vegetation, etc). The *Homogeneous Units* which have been used are *Land Systems*, *Land Units* and *Land elements* (Stewart & Christian, 1968; Mabbutt & Stewart, 1973), as listed next:

Land Elements are equivalent to the *Sites* of Stewart & Christian (1968), i.e., highly homogeneous units in correspondence with specific and clearly bounded landforms.

Land Units are usually (Stewart & Christian, 1968) a group of related sites with a particular land form within the land system and wherever it occurs again it would have the same association of sites. Land Units have been established mostly based upon morphological and lithological features.

Land Systems are (Stewart & Christian, 1968) geomorphologically and geographically associated to the form patterns in the landscape. The boundary of the pattern generally coincides with some discernible geological or geomorphological feature or process. Land Systems are defined following dominant morphodynamic characteristics and processes.

Artieda (1996) applied these subdivisions to draw a map of areas internally homogeneous but distinct. Land Elements show fairly precise spatial boundaries. Contrariwise, the definition of Land Units and Land systems is much more subjective and the limits between them are not so clear.

3.2.5.2.2. Land Systems and Land Units in Quinto

A Land Unit is an area having relatively homogeneous features (geological, biological, edaphic, anthropic and other) from which the land can be visually characterised. Once the Land Units were established their main lithological and geomorphological features were analysed, and further used as a tool to establish soil-geomorphology relationships.

The ten Land Units established in Quinto were named from local toponymy whenever it was possible, next they were grouped in two distinct Land Systems (Table 3.2.3). The soil profiles that will be visited are in the Units marked with asterisk. These are the only Units described in this guide book; full descriptions of all Units can be found in Artieda (1996).

Table 3.2.3. Systems and Land Units in Quinto area.

Land Systems	Land Units
Huerta	Huerta*
Monte	La Tosqueta
	Pilón de la Cabeza
	Umbría de Valdecara
	Las Lomas*
	Escudero-Campillo
	El Planerón
	Lopín
	Fortín
	El Saso-Valdezurrones*

The following sections present the geomorphological and lithological characteristics of the two Land Systems and the two Land Units where soil profiles will be visited. In these Land Units the different soil types existing within various Land Elements are also presented. Soil-landscape relationships are in some cases illustrated by means of toposequences referred to the morphology of the most common genetic horizons. More information of the soil-landscape relationships as well as about modal soil characteristics may be found in Artieda (1996).

Land System Huerta

The main variables defining the Land System "Huerta" are morphology, type of underlying sediments and current processes, being the two first consequence of the third. This Land System comprises the areas close to the Ebro river channel, which are clearly under the influence of fluvial processes. It includes the T1 and part of the T2 terraces within the Ebro Fluvial Complex, and is formed by a group of abandoned meanders and central and lateral bars; a clear escarpment separates T1 from T2. The Huerta System (about 2000 ha) roughly match the old irrigated lands. The relict landforms (old river meanders) evidence a displacement of the Ebro river channel up to N while forming the lower alluvial level. Big dams upstream Ebro river and the construction of dikes for flood protection have modified the evolution of the System.

Land System "Monte"

Contrariwise, lithology of the Land System "Monte" is dominated by lutites with limestones and gyprock levels. Such materials led to a structural tabular relief, with platforms, mesas, cuestas and structural plains, on which alluvial and colluvial deposits are placed. Other characteristic of the Monte is the aridity, being runoff and physical weathering the most active processes linked to strong thermic and pluviometric contrasts as well as to the unfrequent and torrential rainstorms.

The soils of the Monte System are interesting because of the aridity and because some parts of the System are irrigated since twelve years ago

Land Unit "Las Lomas"

The Unit, in the West end of Quinto, will be visited in the Stop 2, and is characterised by the undulate forms, an effect of the sequence of val and undulate relief, that can be seen in the aerial photograms as photolineations with a direction N 130° - E 150°.

The Tertiary substratum is made of lutites with gyprock intercalations and thin calcareous strata belonging to the lower Atalaya Lithological Unit (Artieda, 1993).

Four main kinds of forms are distinguished within this Land Unit: *undulate reliefs, vales, mesas, and structural steps.*

In the *undulate reliefs* culminating in limestone, the soil development is negligible, and rock is bare. If the top is gyprock, the weathering forms are very common, and show specific morphologies (Artieda, 1993) due to dissolution-precipitation processes.

Mesas are topped by limestone or gyprock layers. The main difference with undulate reliefs is the higher topographic relief on the base surface. Mesas occur in the NE border of this Unit, together with several *structural steps* of small surface.

The soil distribution on the different land elements of this Unit is displayed in the Table 3.2.4, and the Figure 3.2.6 shows the studied toposequence.

Table 3.2.4. Classification and genetic horizons of soils developed within several Land Elements of the Land Unit "Las Lomas"

Land Element	**Soil classification (SSS, 1994)**	**Sequence of genetic horizons**
Hillslopes	Lithic Haplogypsids Leptic Haplogypsids	Ay(Y)-By(Y)-R Ay(Y)-By(Y)-Cry-R
Undulate structural reliefs, mesas and structural steps in gypsum	Typic Torriorthents Leptic Haplogypsids Lithic Haplogypsids	A-Bw-Cry-R Ay(Y)-By(Y)-R Ay(Y)-By(Y)-R
Bottom of valleys (vales)	Typic Haplogypsids Sodic Haplogypsids	Apy-By(Y)-R; Ap-Bw-By(Y)-Cry Ap-Bwy-Cry; Ap-Bwyz-Cry

The Leptic and Lithic Haplogypsids have Ay(Y) and By(Y) horizons of flour-like gypsum. The limit between the horizons is conflictive, moreover the By(Y) horizon has decimetric fragments of gyprock that suggest a ruptic character that is not provided by the Gypsids suborder of Soil Taxonomy (SSS, 1994).

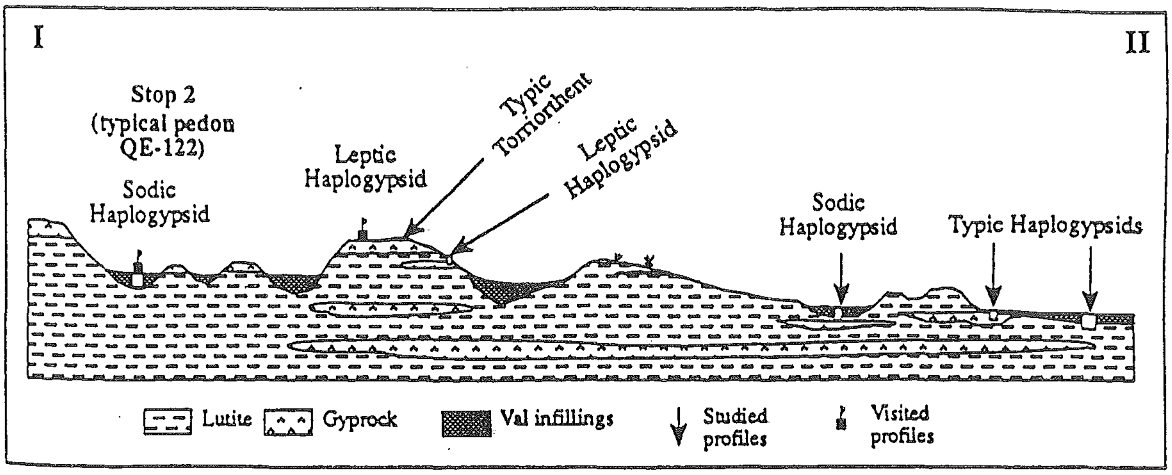

Figure 3.2.6. Toposequence studied by Artieda (1996) in the Land Unit "Las Lomas".

In the Typic and Sodic Haplogypsids, the Bwy horizons show frequent vermiform accumulations of gypsum. Some of the Sodic have saline accumulations, and Bwyz horizons appear. One of these profiles, (QE-122), will be visited in the Stop 2.

Land Unit "El Saso-Valdezurrones"

The Northern limit of this Unit is the Valdecara Barranco. The head of the barranco flows through the Unit and forms an escarpment of about 30 m high at the outlet. The Eastern limit is escarped and corresponds to the Land Unit "Fortín". The Western margin has regular hillslopes and glacis merging with the upper Land Units ("Las Lomas" and "Escudero-Campillo") through slightly sloping contact depressions, that can be considered as shallowly-incised valley bottoms with diffuse limits.

This Land Unit occupies a wide platform formed over limestone strata, 2 m thick, underlying a 30 m deposit of reddish lutites with some centimetric and decimetric gypsum interbeddings belonging to the Lithological Unit "Esquilzo" (Artieda, 1993).

Over the limestone platform several isolated forms appear: limestone mesas, conic hills and old terraces of the Ebro Fluvial Complex (Figure 3.2.7), as well as many opened and closed depressions.

The limestone mesas over the platform are the Loma del Esquilzo and the Loma de Cornero (Stop 1). At the top of the latter is the pond that was built to supply water to the new irrigated lands. This water is brought to the top from the Ebro river, which is more than one hundred meters below. These two mesas have an elongated shape and are mainly formed by a succession of lutites, gyprock and limestones. The lutites increase to the base. The merging of these mesas to the platform is through regular hillslopes and glacis, covered by deposits of different thickness. At their distal part they overlie opened or closed depressions with little relief.

In the northern limit of the platform some fluvial deposits appear, corresponding to old terraces of the Ebro fluvial complex, overlying directly on limestones through an erosive contact that can be seen in some areas. Over these fluvial deposits some materials corresponding to disconnected glacis may appear.

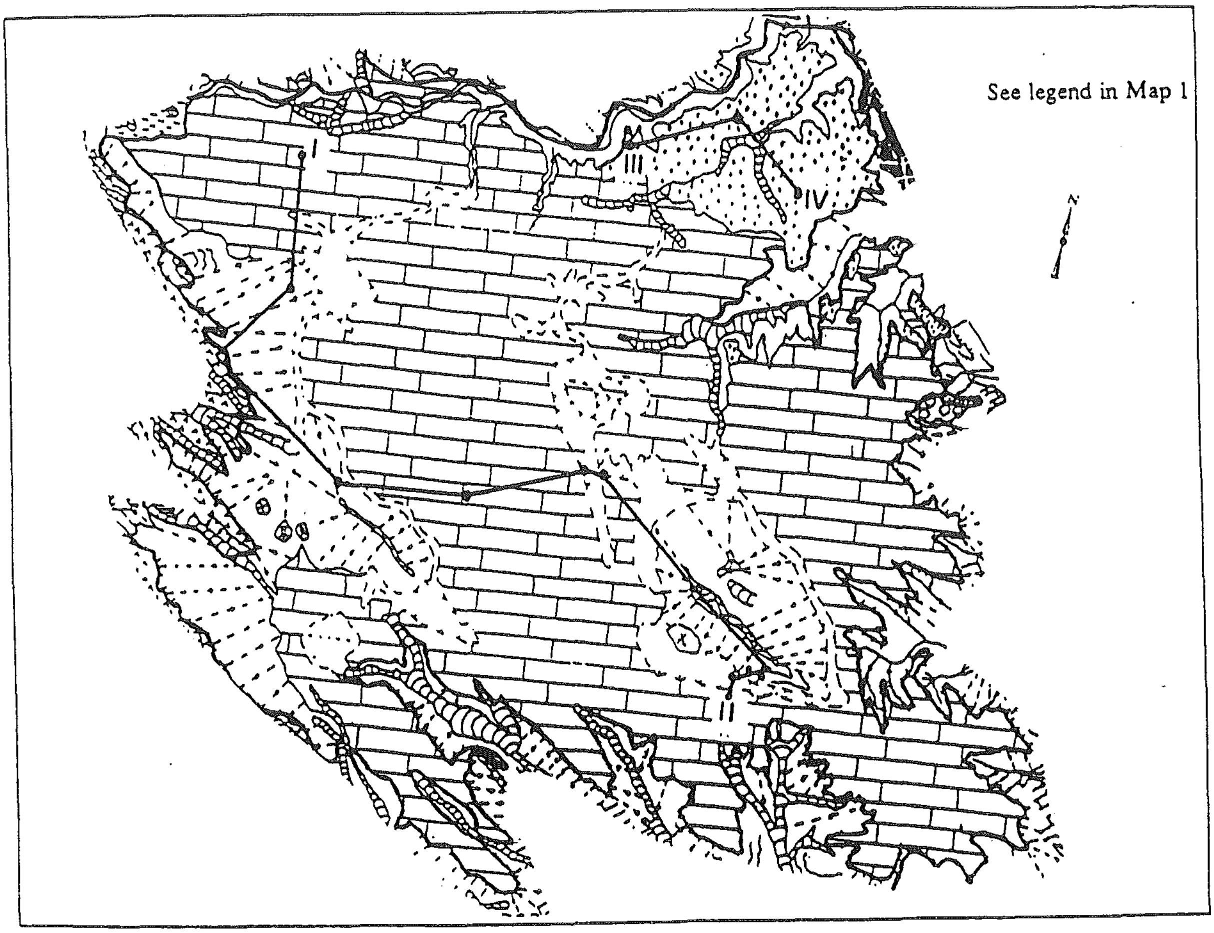

Figure 3.2.7. Geomorphological scheme (E 1: 70.000) of the Land Unit "El Saso-Valdezurrones".

The soil distribution on the Land Element where they have developed is summarized in Table 3.2.5 and is shown in the Figures 3.2.8 and 3.2.9 through two toposequences.

Table 3.2.5. Classification and genetic horizons of the soils developed in the different Land Elements of the land unit "El Saso-Valdezurrones".

Land Element	Soil classification (SSS, 1994)	Sequence of genetic horizons
Limestone platform	Typic Haplogypsids Lithic Haplogypsids	Ap-By(Y)-C/R; Ap-Bw-By(Y)-Cry-R;
Regular slopes and subactual glacis	Typic Torriorthents Sodic Haplogypsids	Ap-Bw-Bwy-R; Ap-Cry Ap-Bwyz-Bwyz; Az-Bwyz-Cr
Depressions	Typic Torrifluvent Sodic Haplocalcids	Ap-Bw-Bwy-Bwyz-R Ap-Bwk-C-Cr/R;
River terraces	Leptic Haplogypsids Typic Haplogypsids Typic Haplocalcids	Ap-By(Y)-By Ap-Bw-By Ap-Bwkn-Ck

The soils developed on the platform are very stony. The coarse elements are tabular-angular limestones.

A common characteristic of these soils is the presence of a By (Y) horizon of flour-like gypsum, light greyish or very pale brown, with textures from medium to moderately fine.

Their upper limit is found at 20 to 45 cm depth, directly under an Ap, Bwy or Bw. Limestone or lutitic levels underlay the By(Y) horizon.

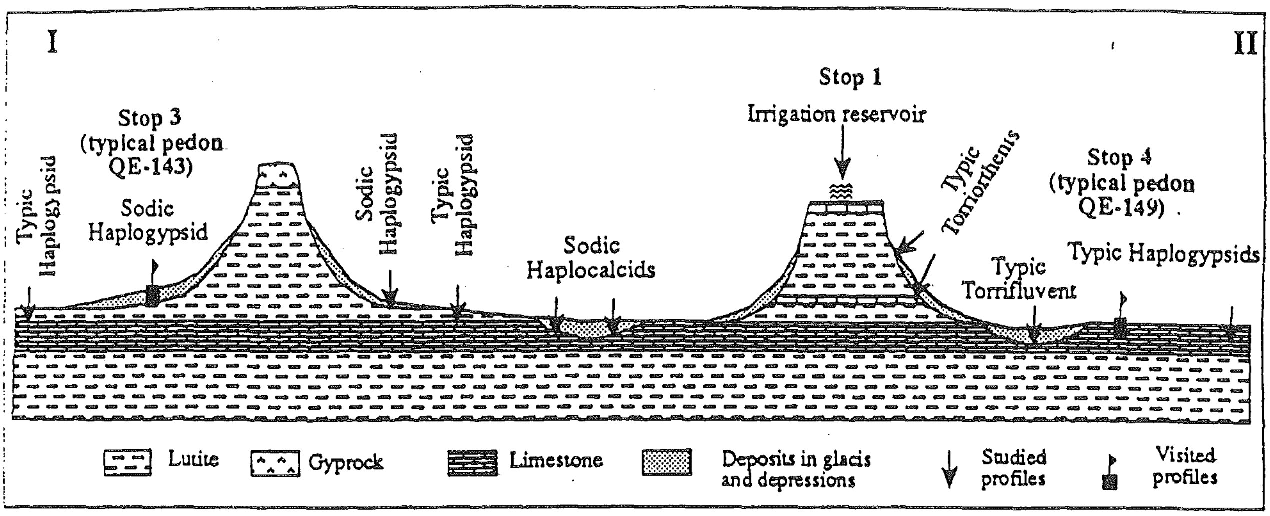

Figure 3.2.8. Toposequence studied by Artieda (1996) according to the transect I-II displayed in Figure 3.2.7.

Typic Torriorthents and Sodic Haplogypsids appear (SSS, 1994) in the regular hillslopes and glacis. These soils are shallow when developed on the upper parts, and deep to very deep if developed in medium or distal zones. In these soils horizons Bwyz appear, with bright faces in the peds and slickensides, although they do not reach 1% in volume. Moreover high salt contents are not rare. Gypsum accumulations appear as nodules, lenticular crystals and vermiform gypsum, reaching even more than 40% in volume.

An Byz horizon with slickensides can be observed in the profile QE-143 (Figure 3.2.8), that will be visited in the Stop 3 of the excursion. Nevertheless, the mineralogical analyses give some uncertainity because from three samples studied in the same horizon one indicates the presence of swelling clays and the others not. These data will be discussed in the point 3.2.5.3.6, where some hypothesis about these features will be presented.

The B horizons of the soils developed on fluvial terraces (Figure 3.2.9) have proportions of coarse elements from few to very frequent. Gypsum accumulations are found as pendents or as fine crystals, whilst carbonate accumulations are as pendants and nodules, giving rise to Bkny horizons. Moreover, the presence of By (Y) of flour-like gypsum is not seldom. The latter presents sometimes vertical joints that individualize blocks of metric size.

The carbonate accumulations appear in the soils developed on depressions and on fluvial terraces, as pendants in the base of coarse elements or as millimetric nodules leading to Bwkn horizons.

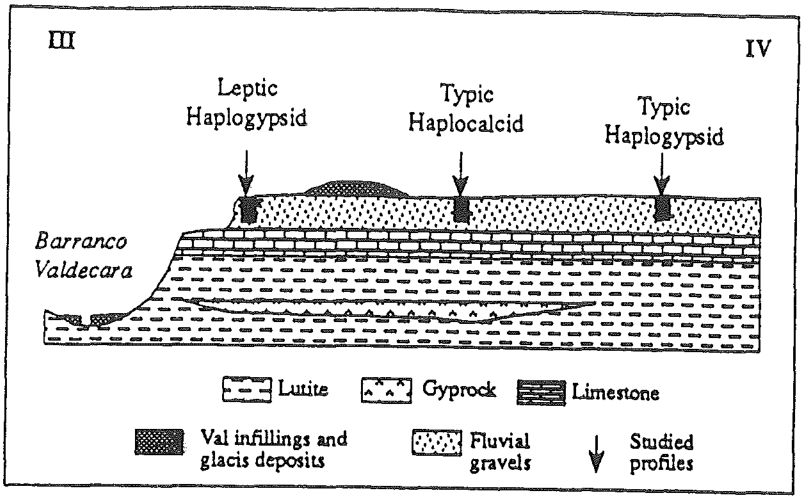

Figura 3.2.9. Toposequence studied by Artieda (1996) according to the transect III-IV displayed in Figure 3.2.7.

Most of this Unit changed its use to irrigation in 1987, producing a significant change in the water regime of the soils. The limestone joint system provides a permeable level, throughout the joints and cracks system, but the underlying lutitic levels have originated waterlogging in some places which obliged to carry out drainage works. Small depressions, infilled valleys or opened depressions with diffuse limits on the platform allows the lutite outcropping in some areas.

3.2.5.3. *Soil formation in arid and gypsum rich environments*

This section presents some of the soil forming processes that stand out in Quinto.

3.2.5.3.1. Rock weathering

a) Lutites

Subspheroidal disjunction is an evident weathering feature of these rocks. Their subaerial exposure produces the individualization of rounded fragments, but these fragments do not occur in the active fronts of quarries supporting the idea that this is an alteration feature. This fragmentation favours the desaggregation and the fluids movement. Desaggregation is also produced by salt-crystal growth, if the lutite contains soluble salts. These morphologies seem not linked to a specific mineralogical composition. The X-rays analyses of seven samples did not show a clear relationship between disjunction and the presence of swelling clays.

On the other hand, the lutites alteration in subsurface conditions seems a different process. Lenticular gypsum often grows in characteristic Cry horizons, occurring as single crystals or as centimetric desert roses. Sometimes the accumulation is so dense that the material looks like sand. The process of lutites alteration is very difficult to separate from the gypsum translocation. In thin section, the advanced stages of destruction of the fresh lutite by interstitial gypsum appears as isles fabric (Herrero and Porta, 1987), i. e., masses of fine material included in a crystalline pedofeature, in this case a mass of lenticular gypsum.

b) Limestones

The limestones are the most coherent and the less weatherable rocks in Quinto. Their chemical alteration is controlled by the solubility of carbonates.

From the four main parameters CO_2 concentration, pH, temperature, and presence of other salts affecting the dissolution of limestones, only the last one will be here portrayed. The salts affect the carbonates solubility because of the changes in the activity coefficients of Ca^{2+} and HCO_3^-, and because of the common ion effect. Using different solvents in laboratory on limestone samples of the central Ebro Valley, Berga (1993) reported that the maximum of dissolved limestone after 10 weeks of contact with distilled water is < 0.02% of the sample weight, and the ratios are similar when the time of contact is only 6 days. If the dissolvent is water saturated with gypsum or with Na^+ (32 g/L), the percentage of solubilized sample is about 0.2% and 0.3% respectively, after a contact of 6 days. These values show the relationship between the processes of weathering of the carbonatic materials and the presence of gypsum.

c) Gypsum

Artieda (1996) reviewed some of the properties of calcium sulfate and its mineral phases: gypsum ($CaSO_4 . 2H_2O$), bassanite ($CaSO_4 . 1/2H_2O$), and anhydrite ($CaSO_4$), and pointed out that in Quinto only gypsum appears as a stable form, at times with relict anhydrite inside the gyprock which has suffered diagenesis.

The term "alabastrine gypsum" is here applied to gypsum that has suffered diagenic processes commonly evidenced by the presence of n.u.e.c. (non uniform extinction components) or anhydrite relics in the thin sections.
Dissolution is one of the processes that affect gypsum weathering. Jauzein (1974) gives a solubility graph of gypsum, bassanite and anhydrite, as a function of temperature (Figure 3.2.10). Concentration of salts in the solution strongly affects gypsum solubility. In pure water it has a maximum of 2.1 g/l at 35-40 ^{o}C, while it reaches 7 g/l in solutions with 120-130 g/l of sodium or magnesium chloride at room temperature (Pouget, 1968). CO_2 pressure also affects gypsum solubility when carbonates are present, due to the increase of Ca^{++} in the solution (common ion effect), and the consequent reduction of solubility. Another factor that affects gypsum solubility is the presence of some organic substances.

Tena *et al.* (1984) pointed out the importance of the texture of gypsum on the solubility of the rock. They suggest that the alabastrine gypsum dissolves only at the surface and slowly, due to the microscopic and submicroscopic size of the crystals, their interpenetration, their high mineral purity, as well as the very low porosity. The megacrystaline gypsum, lenticular and other varieties associated to lutites and carbonated material, present a faster dissolution, due to a higher porosity and discontinuities. Similar conclusions were obtained by Alberto and Navas (1988).

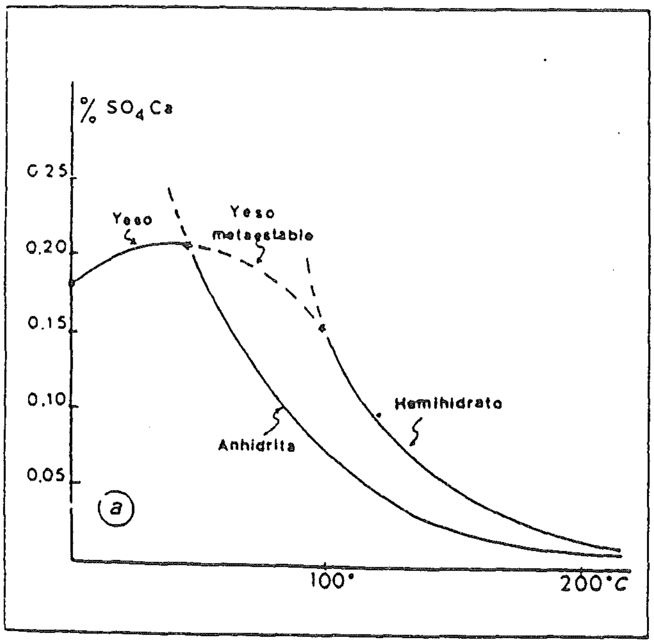

Figure 3.2.10 Solubility in pure water of the different phases of the $CaSO_4 \cdot nH_2O$ *system, as a function of temperature (in Jauzein, 1974).*

Haloclastia is another weathering factor in gyprock. Volume increase and crystallization pressure inside the rocks can break them (Tena *et al.*, 1984). The disintegrated grains are easily eliminated by eolic action, by runoff or by gravity. If these grains remain in situ and are subject to chemical processes of dissolution-precipitation, they can become aggregates that allow the settlement of lichens and lower plants, that in turn can provoke other dissolution-precipitation processes, and eventually form thicker and thicker gypsum accumulations.

Artieda (1993) showed that gypsum crystallization inside gyprock pores or fissures in contact with atmosphere is able to alter these rocks. The appearance of a high porosity by dissolution, produces specific microscopic and typical macromorphological features.

However, the gypsum weathering processes seem different whether they occur on the soil surface or slightly deeper (down to 20 cm). In subsurface conditions, inside the soil s.s., gypsum weathering at a microscopic level, turns to similar fabrics to the ones at surface conditions, being frequent the dissolution pores. Moreover, microcrystaline and larger lenticular gypsum growing are frequent in continuity with the alabastrine gypsum.

The influence of lower organisms on the weathering of these rocks is evident. Moreover, upper organisms, either animals or vegetables, also modify the physical and chemical conditions of the soil.

3.2.5.3.2. Development of edaphic structure

Soil structure is essential to ensure the sustainability of the agrosystem. The degradation of the soil structure by sodication is antagonist with the presence of gypsum. Moreover, clay deflocculation becomes a meaningless concept in soils with almost no clay, like some Quinto's soil with 90% gypsum content.

The presence of gypsum affects the development of structural elements, often because of the channels infilled with gypsum designated as vermiform gypsum in the field. The structural aggregates can be individualized when wet, but the horizon becomes massive and is harder and more compact when dries.

Section 3.2.5.3.1 mentions the weathering effect of gypsum precipitation inside a lutite, creating a poral system. This can be considered a structure formation agent.

When the accumulations of gypsum are important, the morphology and size of the aggregates is strongly conditioned by the morphology, distribution and density of these accumulations. It leads to a strong secondary structure, with aggregates of irregular shapes and with fine or very fine sizes, to an extent that the primary structure is not apparent any more. In these cases, an interaggregate porosity is maintained due to the space between individual gypsum crystals.

3.2.5.3.3. Biopedoturbation

The morphologies associated to the observed processes of biopedoturbation in the studied soils, are essentially a result of root penetration and opening galleries in lutites or other materials allowing further processes. The worms' activity is frequently recognized in the field, and produce a noticeable secondary structure in some soils.

3.2.5.3.4. Erosion-sedimentation

Water and wind are the basic agents responsible for the loss of surface soil in Quinto. Transport of solum-surface particles is common in soils of semiarid areas, where the atmospheric agents, wind and water, are sporadic but powerful. These effects are evident in sloping areas as shown by the presence of rills.

Wind is another erosive agent in Quinto. The critical wind speed values established by several authors (Chepil, 1945; Ortiz, 1990) are probably achieved if we consider the "cierzo" wind speeds (up to 70 km/h, see section 3.2.3.1) and the logarithmic profile of wind on the soil surface (Cuenca, 1989). Soil loss is evident, at least in hectometric or decametric distances, as particles are removed in some areas and deposited nearby, as the decimetrc nebkhas described by Artieda & Herrero (1997) in Fuentes de Ebro.

According to the data of two experimental erosion plots (Gutiérrez *et al.*, 1995) on gyprock near Quinto, the average soil erosion rate is around 1.2 Tm/ha /year, rates being higher on south-facing plots (60%) than on north-facing ones (40%). These values occur in sites where erosion processes are expected to dominate due to the steep slopes, although the behaviour of the gyprock and the covering flour-like gypsum is not well known.

3.2.5.3.5. Salinity and sodicity

Soil salinity refers to a content of salts more soluble than gypsum, that affects the agricultural value of soils. If sodicity, i.e. high exchangeable sodium content, occurs clays are dispersed and structure degraded.

Measures of electrical conductivity and ionic contents (Herrero and Bercero, 1991) in the new irrigated district of Quinto show the small extent of salinity. This is due to drainage schemes, moderate irrigation water applications, and exclusion from irrigation of areas which may have presumably caused problems.

Almost every Land Unit contains areas with saline or saline-alkaline characteristics, and usually these were excluded from irrigation. They are marginal and clearly defined areas. The "Umbría de Valdecara", "Planerón", "Lomas", and "Saso-Valdezurrones" Land Units have some areas with saline and saline-alkaline soils, whereas in the "La Tosqueta", "Pilón de la Cabeza", "Escudero-Campillo" and "Lopín" Units have some areas with saline soils.

The risk of structural degradation is low in these soils, due to the high values of the electrical conductivity of the soil solution and to the ubiquity of gypsum. Thus, only the effects of salinity and of ion-specific toxicity need to be considered.

3.2.5.3.6. Clay mineralogy

The clay mineralogy checked the usefulness of field criteria to detect expansible clays, i.e. slickensides. Results are shown in Table 3.2.6; in 50% of the samples appears a correlation between field detection (presence or absence of slickensides) and the X-ray analysis (presence or absence of expansible clays), whereas in the other 50% of the samples there was no such relation. In 60% of the samples, the presence of both bright ped faces and few, small slickensides has been described on the field. In some cases, as in the thin section of pedon QE-109 (Table 3.2.6), the presence of subhedral carbonate crystals within galleries and fissures is quite remarkable. These crystals can be mistaken for clay coatings due to their brightness.

Table 3.2.6. Relationship between the presence or absence of slickensides in 8 samples of different horizons, and the presence or absence of swelling clays determined by X-ray diffraction of non-oriented aggregates. I/Sm: illite-smectite interstratifieds; Sm: smectites.

Pedon	Depth (cm)	Field-observed slickensides	Bright faces of peds (field)	Coatings in thin section	Clay (%)	Expansible clays (XR)
102	52-62	Yes	Yes	-	49.70	Sm
109	55-95	No	Yes	No	45.79	Sm
115	79-112	Yes	No	-	-	I/Sm
126	60-80	Yes	Yes	No	51.08	No
126	110-127	No	Yes	No	52.38	No
143	120-140	Yes	Yes	-	53.83	No
143	140-160	Yes	Yes	-	52.91	I/Sm
143	101-120	Yes	Yes	No	52.3	No

In other cases, as in the thin section of profile QE-143 (112-120 cm) (Table 3.2.6), numerous pores have mainly lenticular gypsum crystals, whose growth pressure may create small stress surfaces. Repetitions of this process would lead to bigger surfaces. In some cases this is quite obvious, some micas show deformation due to gypsum growth.

The pressure effects of gypsum crystalization have already been mentioned in chapter 3.2.5.3.1. as a cause of gyprock alteration. This crystallization pressure may be considered as the origin of some slickensides. Usually, these morphologies, which are frequent in clayey soils, have been attributed to clay swelling inducing aggregate sliding. But from Table 3.2.6, such relationship is not clear, and some sliding surfaces have been observed in horizons of flour-like gypsum, which suggests some other processes with similar effects.

3.2.5.3.7. Translocation of carbonates

Movement of carbonates through the profile is common in arid and semiarid areas. In our soils, the visible forms of carbonate accumulation are: pendants, soft nodules, and horizons with generalized accumulations that may (petrocalcic horizon) or may not be cemented. The forms occurring in thin section are disperse micrite, needle-shaped crystals, lithorelicts, quesparite, and pore coatings. In some cases, particularly when the groundmass is microgypsic, diffuse coatings of gallery walls are detected which are made up of silt-size carbonate crystals.

3.2.5.3.8. Translocation of gypsum

Gypsum accumulations are frequent in areas with gyprock outcrops, due to the solubility of gypsum (2.6 g/l at 25°C). These accumulations were recognized early by soil scientists.

What we mean with translocation of gypsum is its mobilization, irrespectively of its origin. Gypsum translocation produces different morphologies in different locations within the soil. As the mobilizaton of gypsum by bio-turbation processes has already been mentioned, we shall now discuss gypsum translocation in dissolution.

The dissolution of gypsum may take place before water enters in the soil, by contact between water and surface gypsum materials. It will also take place within the soil due to the presence of gypsum fragments within the matrix. Water tables may also bring gypsum into the soil by capillary rise through gypsum rocks. The latter is the least important mechanism in Monte Land System as there are no regional fluxes. The water table in Huerta Land System is rich in calcium sulfate, and the gypsum precipitation is common.

Gypsic pedofeatures result of surface or irrigation water dissolving calcium sulphate on the surface or within the soil and precipitating gypsum when appropriate physical and chemical conditions develop. The gypsum crystals formed under these conditions always show lenticular or subhedral forms of various sizes.

Some of the morphologies of gypsum in the soils of Quinto are described in the following:

a) Travertinic gypsum

This name refers to the morphology of some gypsum accumulations in gravel deposits. These are cementations of high porosity and prismatic shape, with breadcrumb look (Artieda, 1996).

The generalized presence of these morphologies in a horizon results in a petrogysic horizon, although in some cases the condition of not slaking in water (S.S.S., 1975; 1992) does not hold. This condition is also fulfilled by other types of accumulation.

In Quinto, this morphology has only been observed where polygenic gravels with gyprock fragments are the parent material of soils, i. e. in the fluvial deposits of the Lopín Fluvial Complex and in colluvium from old terraces of the Ebro Fluvial Complex. The presence of gyprock fragments in the parent material raises the hypothesis of a potential source of gypsum, and the existence of dissolution-precipitation processes within the horizon.

Gypsum described in the field as travertinic gypsum looks in thin section as a high porosity (> 50% in some cases) material made up of gravels of different nature, with the gypsum fragments showing clear dissolution features. These gravels are linked by mosaics of gypsum of primary precipitation, with the common presence of discrete masses of microcrystalline lenticular gypsum of millimetric size. Coatings with a thickness up to 1 mm of fragments with lenticular or subhedral crystals of gypsum perpendicular to the surface of the fragment are also frequent.

b) Vermiform gypsum, nodules and coatings

Accumulations of vermiform gypsum are a typical ubiquitous feature in this type of soils, resulting in Bwy and By horizons.

Such accumulations can be referred as macromorphological forms, therefore their features can be recognized visually or using a lens. They correspond with pseudomicelia reported by Stoops & Ilaiwi (1981); however, Porta & Herrero (1988) recommended the term pseudomicelia only for finer accumulations composed by carbonates. This field feature is characterized at microscopic level by coatings and infillings of gypsum on channel and fissure walls. Generally, gypsum is lenticular and subhedral with internal hypidiotopic inequigranular fabric.

Genesis of gypsum coatings and infillings is linked to the movement of calcium sulfate saturated water through pores.

Very often, gypsum accumulations are fragile, millimetric, spherical nodules. Under the microscope, such nodules are composed by gypsum lenticular crystals, both microcrystalline and coarser. This feature indicates a precipitation process, which can be poliphasic surrounding a single point, although precipitation can also be associated with in situ dissolution of gypsum clasts. This type of accumulation is typically found within Apy, Bwy and By horizons.

The coatings of gypsum crystals are occasionally associated to structural elements and more frequently to discontinuity planes of Cry lutitic horizons.

c) Isolated lenticular crystals (intercalary gypsum)

Lenticular gypsum crystals can be found scattered in the groundmass. Sizes vary from 200 µm up to some millimetres. Lutitic-marly impurities parallel to crystal faces indicate phases of development. Epigenesis of carbonates on gypsum crystals can be observed in Quinto. In the studied soils they are characteristic for the Cy horizons, but also appear in the By (Y) horizons.

d) Flour-like gypsum

This kind of accumulation deserves our attention because its limited knowledge and because it is frequent in the gypsum areas of all the Ebro valley.

The term "yerma of gypsic crust" (Kubiena, 1952) was established near Quinto. Other similar terms designing accumulations of gypsum are: crust or crusting (Coque, 1954-55; Bureau & Roederer, 1961), gypsiferous silts (Llamas, 1962; Torras y Riba, 1967-68), flour-like gypsum (Neher & Bailey, 1976). The genetic and less descriptive approach of some documents hampers identification and leads to confusion. Watson (1979, 1980) reviewed many studies on this kind of material.

Porta and Herrero (1988) described a material composed by gypsum crystals of lozenge section with sharp angles, smaller than 15 µm. It was named microcrystalline gypsum. Its touch is floury, and when moist is white-rose coloured. Flour-like gypsum formations are frequent in Quinto containing more than 60% gypsum, and up to 10 % of calcium carbonate.

Figure 3.2.11 shows several locations where flour-like gypsum can be observed in Quinto.

- Flour-like gypsum intercalated or overlying detritic deposits
- Flour-like gypsum intercalated between limestone layers
- Flour-like gypsum on top of any Tertiary materials
- Flour-like gypsum in close contact with gyprock
- Flour-like gypsum covering hillslopes, infilling valleys, forming fans, etc.

Flour-like gypsum in soils on alluvial deposits

Many soils developed on alluvial deposits or colluvium from old alluvial terraces show By(Y) horizons of flour-like gypsum with coarse materials (Figure 3.2.11, position 1). The depth of such horizons is variable, being also observed on the soil surface reaching depths down to 1 meter. Occasionally they have a decimetric prismatic structure, similar to that reported by Coque (1954-55); its adscription to edaphic structure is arguable. The frequent occurrence of coarse elements with fissures infilled by flour-like gypsum have to be considered when determining the genesis.

The flour-like gypsum in gravel quarries is always at surface positions, never more than 2 m deep.

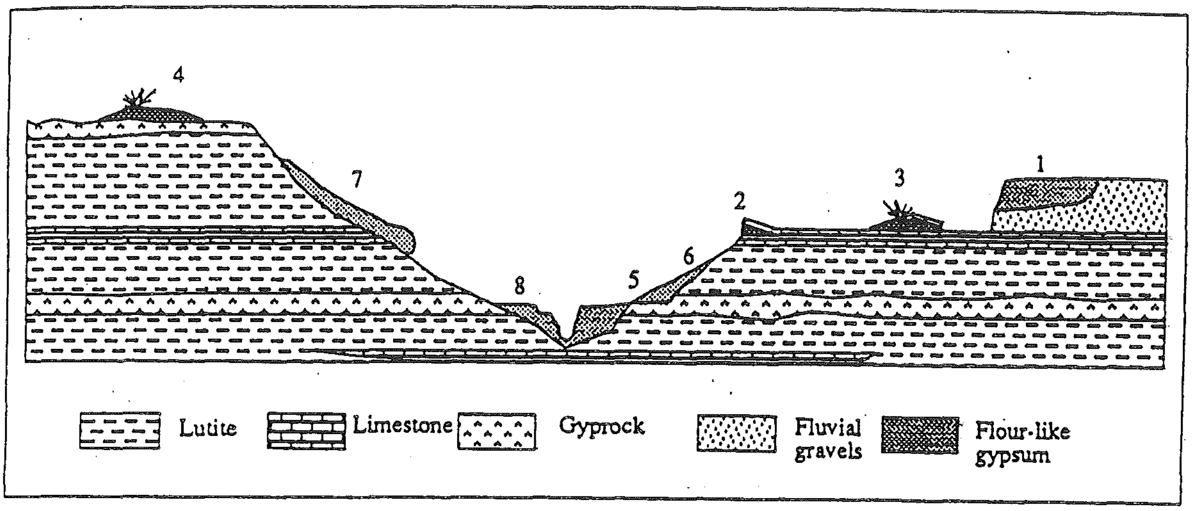

Figure 3.2.11. Scheme of the spatial distribution of flour-like gypsum: 1) Intercalated or overlying fluvial gravelly deposits or gravelly colluvium of fluvial origin, 2) Intercalated limestone strata forming 'ensaimadas', 3 and 4) Topping positions, 5) In close contact with gyprock, 6) As hillslopes deposits, 7) Constituting fans and 8) Infilling valley bottoms. (Artieda, 1996).

Coexistence of flour-like gypsum horizons and travertine gypsum cemented horizons (petrogypsic) within the same profile, illustrate the difficulties to assess the original causes of such morphology. Moreover, horizons of flour-like gypsum reach occasionally a higher degree of compactness than travertine gypsum, so that they could be classified as petrogypsic, as happens in some soils developed in terraces of the land unit 'La Tosqueta'. In thin section, a groundmass of lenticular microcrystaline gypsum can be observed, with some irregular areas constituted by mosaics, sometimes together with prismatic-like crystals.

Flour-like gypsum in soils on structural reliefs over limestone rocks

By(Y) flour-like gypsum horizons in soils on platforms, mesas and limestone structural plains are frequent in Quinto. Soil profiles are generally Ap-By(Y)-Cy-R or Ap-By(Y)-R; profiles Ap-By(Y)-R-By(Y) with flour-like gypsum intercalated (as fissure infillings) within layers of the Tertiary limestones can also be found (Stop 3).

Intrusion of flour-like gypsum trough gully sides, mesas and platforms scarp sides can dislocate the limestone layers (Figure 3.2.11, position 2), resulting antiforms named 'ensaimadas' (Artieda, 1993). Intrusion produces also metric doms, often partially destroyed by agriculture or by intensive intrusion; subvertical limestone steep grounds (lajas) are frequent in non-cultivated areas.

The structural landforms topped by limestone use to contain flour-like gypsum; such feature is clearly evidenced by a white top layer.

Flour-like gypsum at the soil surface

Y horizons of superficial flour-like gypsum occur in Quinto (Figure 3.2.11, positions 3 and 4), both over limestone or gyprock. Horizons are usually less than 0.5 meters thick, being their lateral extension more variable; they are doms of decametric extension, usually fallow land colonized by natural vegetation. Relationship between flour-like gypsum and gypsic rocks allows sometimes to reach a more precise understanding of the genesis (see next section).

Flour-like gypsum in contact with gyprock

These materials can not be found linked to Miocene gypsum layers in quarries and other man made talus, thus, their origin might be related to subaerial exposure as well as to alteration of Tertiary gypsum (Figure 3.2.11 position 5), as stated by Mandado *et al.* (1984).

Occasionally the flour-like gypsum appears to be clearly related to exposure of gypsum strata. Its aspect is similar to other flour-like gypsum but the layout is quasi-concordant with the limiting or enclosed gyprock strata; nevertheless, the contact between gyprock and flour-like gypsum is rather diffuse. The lateral transition between unaltered rock and flour-like gypsum appears generally covered by similar materials which might have been transported downslope.

Flour-like gypsum covering hillslopes and forming fans, infilled valley bottoms ...

An eolian-fluvial origin of the gypsiferous silts on hillslopes and infilled valley bottoms (Figure 3.2.11, positions 6, 7, and 8) has been proposed by several authors. Zuidam (1976) states that most of the silty material infilling valleys comes from erosion of ancient soils on top of the hills, transported by surface runoff in periods of sparse vegetation.

Porta & Herrero (1990) reported mudflows of flour-like gypsum. Such phenomena are not frequent in Quinto; however, when it appears, fans are usually composed by flour-like gypsum which comes, preferently, from the summit of structural reliefs.

In gently slopes and distal cuesta footslopes there are accumulations which can be described in the field as flour-like gypsum. However, in some places brown colour and coarse size-distribution make classification as flour-like gypsum more risky.

Morphological characteristics of the flour-like gypsum

The micromorphological study of these materials show that they are mainly formed by lenticular microcrystalline gypsum forming a continuous mass, namely the microgypsic groundmass (Herrero, 1991). Nevertheless, in some cases it appears as microgypsic-carbonatic or microgypsic-silicatic (flour-like gypsum samples from the positions 4, 6, 7 in Figure 3.2.11), depending on the amount of fine carbonatic or silicatic material.

Within this groundmass coarse elements of different origin appear. Tabular subrounded or subangular limestone fragments, up to 1 mm in diameter are frequent in all the samples, at different percentages, reaching sometimes 5%. Quartz fragments represent not more than

1%, appearing only in Y horizons of soils developed on fluvial deposits. Gypsum clasts with dissolution features with pendent-like fabric (Artieda 1993) are found in those samples corresponding to the positions 4, 6, 7 and 8 shown in Figure 3.2.11. Among organic components, vegetal residues are common in all samples.

The most frequent pedofeatures are gypsum infillings and coatings in galleries, but carbonatic silt coatings also appear. Single quesparite grains and quemosaics occur in some cases. Nodules made by microcrystalline lenticular gypsum appear in almost all samples, as well as lenticular gypsum crystals (< 1mm) showing growth lines.

The most common microstructure is an horizontal or vertical lamination, due to the interbedding of layers with different crystal size, or due to fissures. The granular or massive structure is neither uncommon. In other cases the look of the groundmass under parallel polarizers is a rather polygonal network made of fine threads, close to those interpreted by Herrero (1991) as root hairs or hyphae.

Chemical and physical characteristics

Typical flour-like gypsum exceeds 70% of gypsum content, although in the positions 4, 6, 7 and 8 (Figure 3.2.11) the percentages are lower reaching 45% as the minimal value. The next component in abundance are the carbonates. Their modal content is 5% of equivalent calcium carbonate, reaching up to 13% in the same positions; pH values are neutral or slightly basic; EC in the 1:5 extract seldom exceeds 4 dS/m at 25ºC.

Genesis of flour-like gypsum

According to Herrero (1991), the microcrystalline lenticular gypsum is formed by dissolution of calcium sulphate-rich rocks and immediate precipitation of microcrystalline gypsum. A possible role played by lichens or by root remains is not disregarded. This mass undergoes continuous dissolution and precipitation causing an homogeneization and purification, through the elimination of the carbonatic and silicatic materials either by dissolution or translocation. This model does not allow to explain the flour-like gypsum found between fluvial gravels or limestone strata; therefore a precipitation from further sources from calcium sulphate-saturated waters must be considered.

Proposed genetic model for flour-like gypsum in soils developed on limestone structural landforms

The proposed model can be summarized (Figure 3.2.12) in:

1.- Either erosion or outcropping of the limestone.

2.- The vadose water that wets those materials flows to the exposed parts due to the different hydraulic potential which have their origin either on the incision processes or, merely, on the evaporation processes through joints. That water is oversaturated on calcium sulphate.

3.- When the water front reaches the rock/air interphase, evaporation and gypsum precipitation occurs on those zones. Successive cycles of the process cause the deformation of the upper layers due to gypsum cristallization pressure.

The displacement of limestone strata can be explained by the pressure generated by nucleation processes and cristalline growth in gypsum concentrations. The same process, at a microscopical scale, leads to the disaggregation of limestone fragments due to the displacive growth of prismatic or lenticular gypsum. Figure 3.2.12 summarizes the process for the formation of 'ensaimadas' and simultaneously for the formation of the soils with an Ap-Y-R or Ap-Y-Cry horizon sequence. These soils have been developed on flat structural platforms on limestone. Formation of horizons with flour-like gypsum on soils developed on gravel material follows a very similar process.

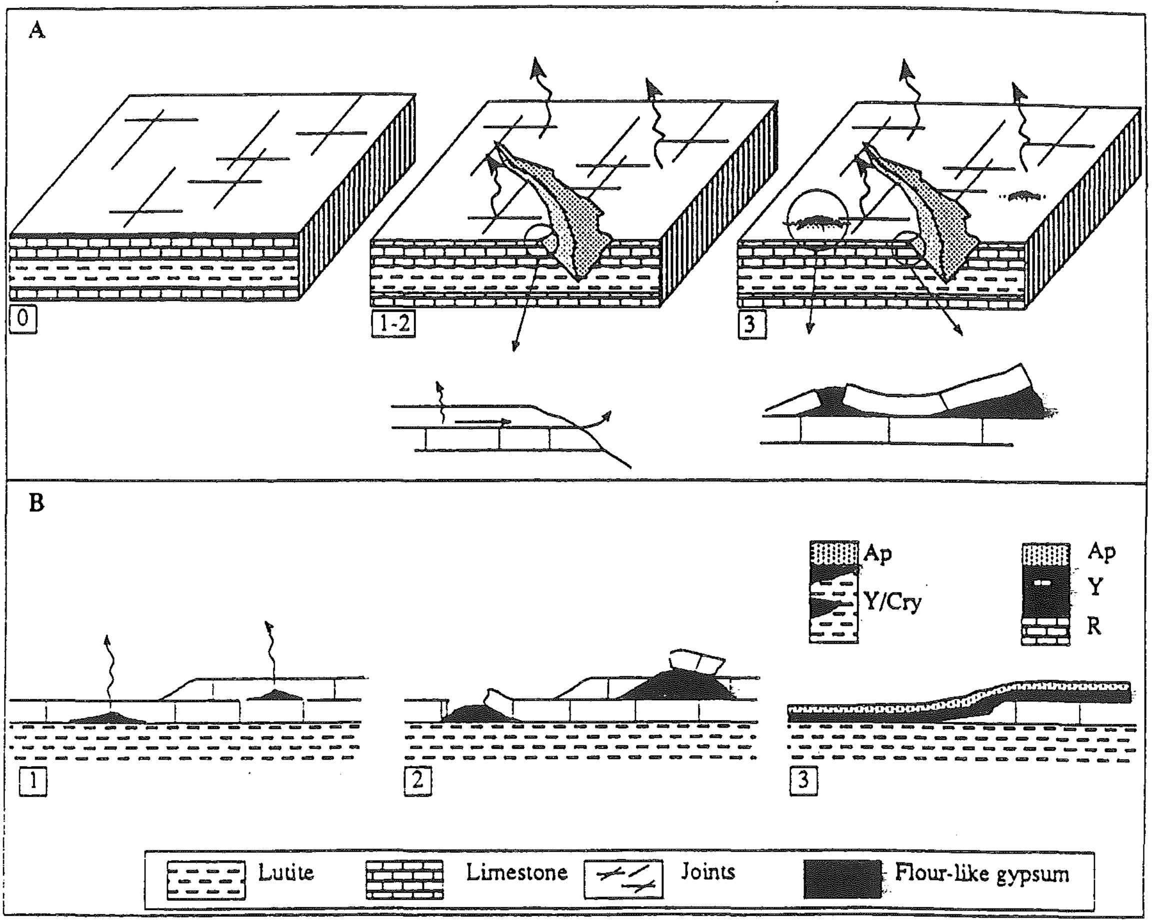

Figure 3.2.12. A) Model of the formation of "ensaimadas" (flour-like gypsum intruding limestone estrata), and associated forms. 0: Starting. B: Model for the genesis of soils Ap-Y-R or Ap-Y-Cr (Artieda, 1996).

Micromorphological studies of these horizons showed that they were formed by lenticular gypsum of different sizes. In some cases there was a clear predominance of microcrystalline gypsum, with disperse lenticular crystals of larger sizes (up to 1.5 mm). In other cases, millimetric lenticular gypsum predominates, together with some irregular microcrystalline concretions. In any case limestone fragments, up to a diameter of 6 mm, are frequent and they show evident disaggregation features due to displacive growth of gypsum. It is observed that the larger the gypsum crystal size, the more frequent fissuration features are. In the same way processes of translocation of carbonates with irregular epigenesis are evident on lenticular gypsum crystals. Vughs and galleries can be found in different proportions in all the studied samples.

The above mentioned differences on the size of the crystals influence the feel determination of the texture of this layers. Particle size analysis is impossible to carry out in most cases. Anyway, there are some exceptions where this analysis is possible. Table 3.2.7 and Figure 3.2.13 show some analytical data from soil QE-180, with the sequence Ap-

By1(Y1)-By2(Y2)-R of genetic horizons. Layers By(Y) are flour-like gypsum, with a rough feeling.

Table 3.2.7. Analytical data from the soil profile QE-180

Horizon	Depth cm	pH H_2O 1:2.5	ECe dS/m at 25 °C	Equivalent calcium carbonate %	Equivalent gypsum %	Organic matter %
Ap	0-30	7.7	5.5	32.5	-	1.6
By1(Y1)	30-72	7.8	5.2	10.3	87	0.6
By2(Y2)	72-114	7.9	5.7	20.2	75	0.4

Figure 3.2.13 shows the textural differences between By1(Y1) and By2(Y2) horizons. Silt fraction dominates in the first one and sand fraction in the second one. Moreover, it can be observed (Table 3.2.7) a lower gypsum content in By2(Y2) horizon than in By1(Y1). The same table shows that calcium carbonate follows the opposite trend. Those facts, together with the above mentioned micromorphological variability suggest that a process of progressive enrichment on gypsum, due to a sequence of dissolution and precipitation processes.

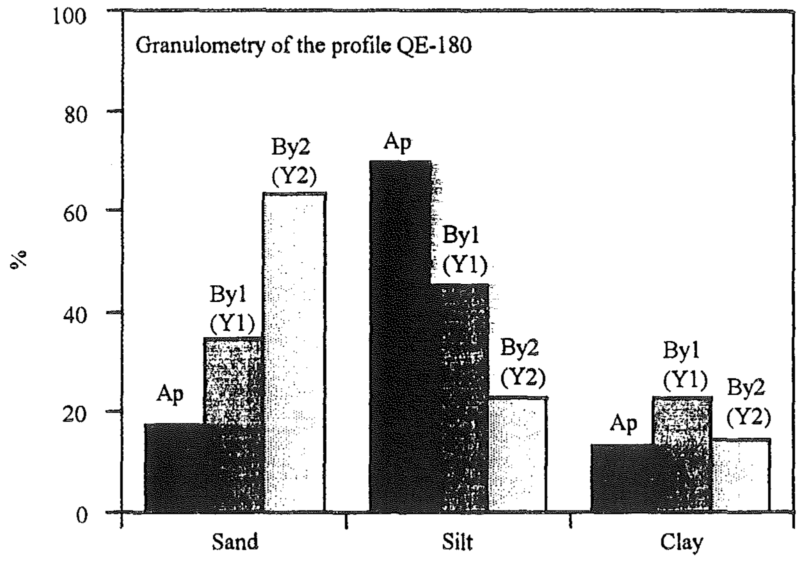

Figure 3.2.13. Sand, silt, and clay percent in the horizons Ap, By1(Y1) and By2(Y2) of the pedon QE-180.

Proposed genetic model for the flour-like gypsum formed in slopes, infilling valleys, forming mudflows

The presence of flour-like gypsum in slopes, infilled valleys, etc. can be explained by the accumulation of flour-like gypsum that is generated in any of the other situations and, mainly, from gypsum in top positions. In addition, microcrystalline gypsum, coming from the precipitation of percolating water has to be considered; as well as the gypsum that can be generated by in situ gyprock weathering, which could be deposited together with other materials.

However, the transport mechanism is not very well established. In the case of slope accumulations, it can be explained by the wind, although short gravitational movements could also be the reason.

In the case of deposits infilling valleys bottoms, gravitational movements could explain these deposits by themselves. Nevertheless, the longitudinal -alluvial- component of the deposits, will probably be more important in the first phases of the infilling process. In thin section flour-like gypsum is an important component of the groundmass, forming millimetric discrete irregular masses.

In the case of mudflows, it seems sensible to think that it is a gravitational movement. The degree of plasticity reached by these materials in wetting will allow their mass movement from top positions (for instance the margin of a structural platform) downslope.

An important aspect, not yet explained, is the causes of the lenticular habit and small size of the crystals. Through some experiments, Cody (1979) studied the environmental conditions controlling the development of lenticular morphologies in gypsum crystals, and concluded that it is mainly due to the presence of organic matter. These data agree with the results of Porta (1986), who found lenticular crystals when gypsum precipitation was produced in an environment with straw residues, whilst the precipitation in sand or in free surfaces originated prismatic morphologies.

In some of the studied samples there is a close relationship between microcrystalline lenticular gypsum and plant residues. It has even been observed microcrystalline gypsum within a vegetal residue. In addition, the microcrystalline mass at the external part of that residue showed a certain channel system which looked as root hairs, which would relate organic activity and microcrystalline lenticular gypsum. In spite of this apparent relationship, the presence of organic matter reduces the number of formed crystals (Cody, 1979), therefore their effects do not explain the features observed in a satisfactory manner. Moreover, further supply of gypsum originates new crystals instead of favouring the growth of the old small ones.

According to Pouget (1968), the formation of small crystals is enhanced when gypsum precipitates in a highly saturated solution. This classical argument explains the small crystal size, although the necessary conditions to cause such supersaturation are still obscure.

From our observations and based on Herrero (1991), a global model is proposed (Figure 3.2.14) to explain the different forms of flour-like gypsum (n.b. flour-like gypsum is the field term for "microcrystalline lenticular gypsum" at the microscope).

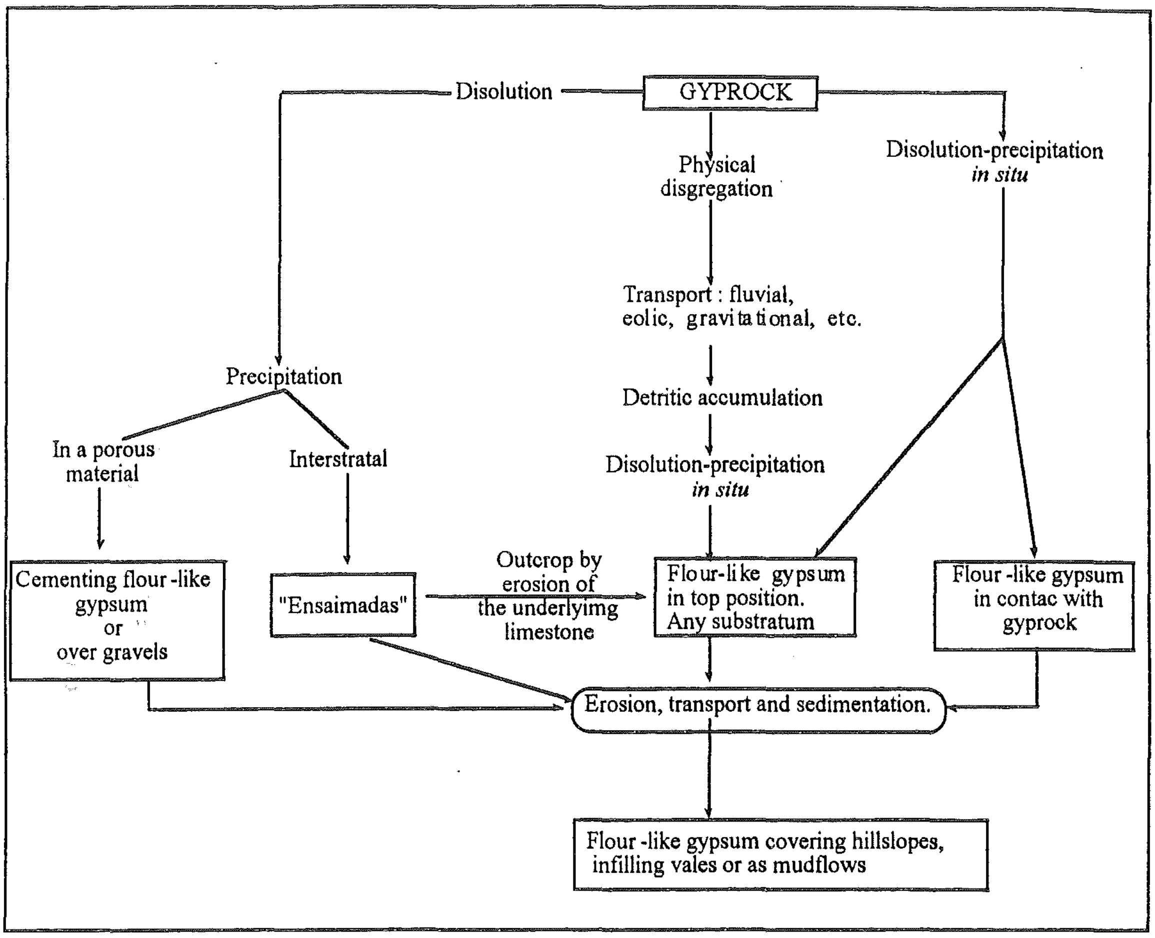

Figure 3.2.14. Global model explaining different forms of flour-like gypsum (Artieda 1996).

The mechanical characteristics of this material allow its ploughing, a practice that would threat its stability when found at the surface. In the long term this would be the cause of changes in the landscape due to agriculture intensification, which should be studied to be taken into account by environmental policies.

3.2.5.4. *Classification of the visited soils* (J. Boixadera and J. Herrero)

Soil classification problems are different in the two Land Systems of Quinto because of their distinct environmental conditions. These problems in Monte Land System are representative of many semiarid areas with ubiquitous gypsum, whereas the problems in Huerta Land System can be similar to other old irrigated areas in the lower terraces of rivers.

The abundance of gypsum affects the applied or engineering aspects of the landuse. That refers to the chemical effects of gypsum on civil works, such as the aggressiveness of waters with gypsum against iron and some concretes or the sinking of irrigated soils due to gypsum dissolution. On the other hand, the effects of salinity in the soils and consequently in the agriculture are less severe because of the large amount of gypsum in soils. Often, the consideration of gypsum in the land evaluation systems is no well suited, and needs some adaptations (Laya *et al.*, 1998).

With the present definition of gypsic horizon in Soil Taxonomy (SSS, 1994, 1996), this diagnostic horizon appears in almost all soils developed in conditions where the gypsum is ubiquitous, as the case of Quinto. This fact makes it very difficult to reflect in the name of the soils the soil-landscape relationships and consequently in the soil maps.

Some of the most trite concepts in soil science are difficult to apply in this environment, which implies the necessity to adapt previous ideas or to introduce new ones. That limitation affects in many ways the knowledge of these soils.

The title of this section refers only to soil classification, but it also includes some genetic aspects affecting the classification.

Field use of Y designation for horizons with very high gypsum content helped field description, regardless of other considerations needed for the use of genetic horizons accepted in the most widespread soil classification systems.

a) Taxonomic problems in Quinto with Soil Taxonomy System at the Order level.

With Soil Taxonomy System (SSS, 1975, 1996) all visited soils in Monte Land System are Aridisols because of the reasons presented in section 3.2.3.3, although actual measures of soil water contents in the soil moisture control section are not available.

Aridic moisture regime seems not acceptable in Huerta Land System, by the reasons sketched in section 3.2.3.3. One could argue that irrigation deserves a different consideration in the two Land Systems. Irrigation in Monte is only ten years old, and depends on an electrical pumping of water from Ebro river and on sprinkling with auxiliary engines. Irrigation in Huerta of Quinto is several centuries old, and according to a roman document of 15 May 87 a.C. (Fatás & Beltrán, 1997) irrigation was probably practiced in pre-roman times in a close area. Irrigation in Huerta is by gravity, and the actual moisture regime of these soils is probably not too much altered if compared with the “natural” regime, before the regulation of Ebro river that flooded this areas one or two times by year in most years. We can conclude that the concept of aridic moisture regime is not adapted to these circumstances that are common to other rivers of the Old World.

Even now, a general groundwater table exists in Huerta. This table supplies moisture to the soils by capillary rise. In this situation, it would be more realistic to consider a xeric soil moisture regime, or even better an ustic moisture regime, considering ustic less water limited than xeric.

b) Problems in the suborder Gypsids.

Denomination and taxonomic location of soils with gypsum has suffered several vicissitudes (Herrero and Porta, 1991). In the case of the Aridisols, the 6th edition of Keys to Soil Taxonomy (SSS, 1994) established the suborder of Gypsids that is maintained in the 7th edition (SSS, 1996).

All the visited soils in the Monte Land System have a gypsic horizon and belong to the Gypsids suborder (Table 3.2.8). Nevertheless, in soils developed in environments where gypsum is ubiquitous, we found problems with the definition of gypsic or petrogypsic horizon established by Soil Taxonomy (SSS, 1994), which requires at least 1% of "visible secondary gypsum" without an explicit criteria to distinguish it from no-secondary gypsum.

b.1) The determination of a gypsic horizon.

When Artieda (1993, 1996) studied the soils of Monte Land System he pointed out, in agreement with several documents cited in his work, the practical impossibility to distinguish accumulated from inherited gypsum in the soil, not only in the field, but also in the thin section. This problem comes out when gypsum in the horizon to be qualified as gypsic is lenticular in a high percentage. The reason is that no characteristics of general applicability are available to differentiate secondary gypsum neither in the field, or in thin section. This problem is disregarded by the soil classification systems. Another example can be found in gypsum presentation as small particles, which makes difficult to determine if they are lithorelics of gyprock, or relics clasts, or dissolution of large lenses. Even when field and thin section analysis show gypsum coming without any doubt from edaphic processes, like the vermiform gypsum, the definition of gypsic horizon is also difficult to apply if these morphologies appear together with gypsum from other origins (as cited before) which are usually present in Quinto.

The same problem is present when applying the gypsic definition to lenticular microcrystalline gypsum horizons, which can be present either almost in pure state or with silicate or carbonate materials and together with larger particles of lenticular gypsum. That is the case of formations of gypseous materials, sometimes containing more than 90% of gypsum, the so-called flour-like gypsum. In Quinto this material creates horizons considered as diagnostic, that appear on gyprock, in gravels, or under limestone (profile QE 149 and stop 4). The same material can be found in other locations within the Ebro watershed, and is similar to those described in other parts of the world (Coque, 1961; Grande, 1967; Neher and Bailey, 1976). A genetic model for this material was propounded by Herrero (1991) and later enlarged by Artieda (1993); anyway, the illuviation concept included in SSS (1994, 1996) is not very appropriate.

On the other hand, when we are in the limit of the morphometric requirements we appeal to the gypsum content obtained from chemical analysis, but that does not give any information about the origin of the gypsum. Even when the gypsum origin is not taken into account, we may have doubts about meeting the content requirements of gypsum when we use some analytical methods unable to quantify the gypsum percent when it is lower than 8% (Artieda, 1993).

When classifying these soils, we have to keep in mind that the exact origin of the gypsum is not important regarding their role in agricultural, environmental, or soil behaviour issues.

b.2) Petrogypsic versus gypsic.

In order to define the petrogypsic horizon, older Keys to Soil Taxonomy included a simple test to evaluate the horizon cementation. Nowadays, the identification of this horizon based on cementation is problematic since that simple test has been eliminated (SSS, 1994, 1996). The lack of morphologic and micromorphologic criteria, together with the evolution of the behaviour of gypsum horizons as a function of their humidity, exposure to high temperatures reachable in arid areas, and other factors not yet studied, have also contributed to the problems in the field identification based in the degree of cementation.

Cementation can be evaluated from the mechanical behaviour, but it does not seem to be defined in microscopic terms. Aggregation mechanisms are different in gypsum from carbonates, which are usually taken as reference. When comparing the initial paragraphs of the gypsic and petrogypsic definitions in SSS (1994), it seems that the increase in the amount of gypsum leads to "cementation". But the flour-like gypsum, even in almost pure state, can often be knife-carved and it disintegrates under finger pressure. Its behaviour as "cemented" after fast drying can be explained by electrostatic forces among microlenses. This fact is the basis to consider it petrogypsic in certain circumstances. If the concept of "cementation" in petrogypsic horizons has many problems for the above mentioned reasons, it is the same for the concept of "indurated" in the revised definition (SSS, 1994).

A sufficiently wide microscopic study should clarify if the petrogypsic character is associated to a mutual linking among gypsum crystals, as it would appear from the cross-sections studied in Quinto, and as is suggested by the field observations. That linking, not seen in flour-like gypsum nor in any other gypsum horizon under the microscope, would give a permanent mechanical behaviour to the horizon. Besides, this is compatible with the characteristics of the travertinic gypsum in Quinto, even with its porosity which would be modified in any way with time or environmental changes.

Nevertheless, it is paradoxical to identify as petrogypsics horizons like the soils defined by the profile QE 135 (not visited), which sometimes have a porosity higher than 50% that may indicate hydraulic properties different from those of a cemented horizon.

c) The Sodic subgroup within the Haplogypsids.

Soils represented by the pedon QE 122 and QE 143 (stops 2 and 3) are included in the same subgroup with the same designation. Efflorescences after precipitations and the colonization of no-cultivated fields with halophytic vegetation indicate the presence of salts more soluble than gypsum.

However, their classification as sodic, even at this level, is questionable from their equivalent gypsum contents, which are higher than 10% in all the horizons to 2 m at least in depth. The discussion should take into account the effects on structural stability not only of gypsum content, but also of the abundance of magnesium ion in the soil solution, where this ion is in a 1:3 ratio with sodium approximately. Even with the lack of applied and theoretical studies, it should be stressed that no structural stability loss signs have been detected after being sprinkled, and the initial waterlogging in the soils with the highest clay content in Quinto agricultural area was solved with the installation of a drainage system.

In order to take into account these points it will suffice to exclude from the Sodic Haplogypsid subgroup the soils with high gypsum content or other soils with other dispositions of the sodium rich horizon in relation with the one rich in gypsum. Moreover, the concept of sodication is meaningless in the soils with low or very low clay content, as it is the case of some gypsic horizons found in the Ebro valley and in other parts of the world.

Another aspect to point out is that fluventic character is not in the subgroup level within the Aridisols, since it only appears in the suborder Cambids of SSS (1996). This character occurs in the visited soils and has land use implications. Then it seems reasonable to claim a Fluventic subgroup in the Haplogypsids.

d) The ruptic character.

Soils represented by the pedon QE 149 and stop 4 have contact with limestone, which fulfills the requirements of a lithic contact. The pedon QE 149 is a Typic because of the depth of the rock; however, that depth varies and the gypsic horizon presents discontinuities. It seems reasonable to include this characteristic of agricultural interest as Lithic-Ruptic Haplogypsid, a subgroup not provided by SSS (1996).

e) Classification of soils in the Huerta Land System.

As above discussed, the main problem with Soil taxonomy System in Huerta is relatet to the concept of soil moisture regime. If a torric moisture is accepted for the pedod QE13, it can be later decided for the Suborder if its moisture regime borders xeric, thus te soil will be a Xeric Torrifluvent, or if it is bordering ustic, because water is available to plants during the summer. In this case the soil would be an Ustic Torrifluvent.

f) Designations following FAO (1990).

Although is not the case of the visited soils, the lack of coincidence in the definition of the gypsic horizon among FAO (1990) and Soil Taxonomy (SSS, 1994) may produce sets of soil names not comparable. Thus FAO (1990) not only keeps the requirement of enrichment in "secondary calcium sulfate" but also the need for more than 5% of gypsum than the underlying C horizon, which has been removed in Soil Taxonomy (SSS, 1994).

In many soils of Quinto, the second condition is fulfilled or it cannot be used either because there is a contact with gyprock or because the great thickness of the B horizon. Considering the fact of the parallelism of the diagnostic horizon definition in both systems, it is valid the former discussion, where the condition for enrichment was skipped.

Because of the nature of FAO legend, the taxa are not appropriate for soil maps at large scales or for detailed soil studies. This is clear in Table 3.2.8, where the visited soils only key out in two of the taxa of the legend, which in the other hand only has four in the Gypsids.

g) Designations following W.R.B. (1998)

As above discussed, the gypsic horizon is a central issue in the classification of these soils. The proposed definition of gypsic horizon by FAO (1998) contains many changes in relation with FAO (1990) or with Soil Taxonomy (SSS, 1994, 1996). The most striking is the gypsum content of 15% instead of 5%; also the amount of secondary gypsum, that is skipped although some secondary gypsum is needed to be considered a gypsic horizon. The exclusion of primary gypsum by W.R.B. (1998, page 39) is problematic by the reasons discussed in the section b.1).

The change in the gypsum content will have limited impact in the names of soils in the Monte Land System, because of the ubiquity of gypsum and its large amounts in many horizons. This is not the case in the Huerta Land System, where the gypsum amounts are lower.

The introduction of a hypergypsic horizon also helps to separate different kinds of soils (Table 3.2.8).

To key out in Gypsisols, the hydromorphic condition is coupled with a gypsum content equal to a gypsic horizon. The meaning of hydromorphic conditions and a content of 15% gypsum by volume should be clarified. Any mention is made in W.R.B. (1998) about what are hydromorphic conditions. Does it meant that gypsum accumulation under hydromorphic conditions is not considered a gypsic horizon? Why? These circumstances can be found in Huerta Land System, and are frequent in similar environments.

In the lower level units, the above criticisms for Sodic subgroups in Soil Taxonomy System, apply to W.R.B. (1998).

Table 3.2.8.- Classification of the profiles visited in Quinto.

Stop	Profile	Soil Taxonomy System (SSS, 1994)	FAO, 1990	W.R.B., 1998
2	QE 122	Sodic Haplogypsid, fine, gypsic, thermic.	Haplic Gypsisol	Endosodic-Haplogypsic Gypsisol
3	QE 143	Sodic Haplogypsid, fine, gypsic, thermic.	Haplic Gypsisol	Sodic-Haplogypsic Gypsisol
4	QE 149	Typic Haplogypsid, coarse silty, gypsic, thermic.	Haplic Gypsisol	Hypergypsic Gypsisol, or Leptic-Hypergypsic Gypsisol
5	QE 13	Xeric Torrifluvent, fine loamy, mixed (calcareous), thermic.	Calcaric Fluvisol	Calcaric Fluvisol

Appendix 3.2.

Stop 1:

Overview of the area to be visited. Arid modelling forms.
Reservoir of the water pumped from the Ebro river, and delivey pipes.
Distintct contrast between drylands and irrigated lands.
Overview of the cropping and irrigation systems.

Stop 2: Sodic Haplogypsids developed in the valleys of the Land Unit "Las Comas"

Stop 3: Typic Haplogypsids developed in the glacis of the Land Unit "El Saso-Valdezurrones"

Stop 4: Typic Haplogypsids developed in the platform of the Land Unit "El Saso-Valdezurrones"

Stop 5: Torrifluvent developed on the lower terrace of the Ebro river, Huerta Land System.

STOP 2: Sodic Haplogypsids developed in the valleys of the Land Unit "Las Lomas".

PEDON QE-122

Reference coordinates on the orthophoto E5 412 10 04
x 702940 y 4586025 z= 250 m

Geomorphology

Landform: valley
Slope: < 5%

Land use: Dry farming; at present fallow. Without vegetation.

Described by: J.M. Salamero. 20/04/90

Classification: Sodic Haplogypsid, fine, gypsic, thermic (SSS, 1994)

PROFILE DESCRIPTION (SINEDARES, CBDSA, 1983)

Ap 0 - 32 cm
Slightly moist; brown (10 YR 4/4); without coarse fragments; silty loam; moderate coarse angular blocky structure no aparent faunal activity; strong reaction to HCl (11%); abrupt (due to ploughing) and clear boundary.

Bwy1 32-75 cm
Slightly moist; dark brown (10 YR 3/4); without coarse fragments; silty clay loam; primary structure: strong, medium angular blocky; secondary structure: very strong, with fine forms due to faunal activity; faunal activity: frequent worm excrements, filled chambers and insect excrements; strong reaction to HCl (11%); frequent vermiform gypsum accumulations, fine, soft and regularly distributed; clear smooth boundary.

Bwyz2 75 - 130 cm
Slightly moist; brown (7.5 YR 4/4); without coarse fragments; silty clay loam; primary structure: strong, coarse angular blocky; secondary structure: moderate, fine forms due to faunal activity; faunal activity: frequent worm excrements and filled channels; strong reaction to Hcl (11%); frequent vermiform gypsum accumulations, fine, soft and distributed all over the horizon; clear smooth boundary.

Bwyz3 130 - 170 cm
Slightly moist; brown (7.5 YR 4/6); without coarse fragments; silty loam; moderate coarse angular bloky structure; faunal activity: frequent filled channels and few galleries; strong reaction to HCl (11%); frequent vermiform gypsum accumulations, fine and medium, soft and distributed all over the horizon; clear smooth boundary.

Bwyz4 170 - 200 cm ↓
Slightly moist; brown (7.5 YR 4/4); silty clay loam; moderate, coarse angular bloky structure; strong reaction to HCl (11%); frequent accumulations of vermiform gypsum, fine, soft and distributed all over the horizon.

ANALYTICAL DATA

Horizon	Depth cm	pH H_2O 1:2,5	E.C. 1:5 dS/m at 25 °C	Calcium carbonate equivalent %	Gypsum equivalent %	Organic matter %
Ap	0-32	8,0	1,2	45,0	11,0	3,8
Bwy1	32-75	8,1	1,8	29,0	15,0	2,1
Bwy2	75-130	8,3	4,7	26,3	19,0	1,7
Bwy3	130-170	8,3	4,8	30,1	19,0	0,7
Bwy4	170-200	8,3	5,1	17,8	29,0	0,7
	125	-	-	-	-	1,2

Granulometry USDA				
Horizon	Sand %	Silt %	Clay %	Classification
Ap	12,35	41,45	46,18	SC
Bwy1	3,36	38,25	58,38	C
Bwy2	10,27	42,78	46,93	SC
Bwy3	8,89	44,64	46,45	SC
Bwy4	3,63	69,25	27,10	SCL

Saturated paste extract

Horizon	Water %	E.C. dS/m	pH	Ca^{++} meq/L	Mg^{++} meq/L	Na^{+} meq/L	SAR	$CO_3^{=}$ meq/L	HCO_3^{-} meq/L	$SO_4^{=}$ meq/L	CL^{-} meq/L
Ap	43,0	2,8	8,2	32,70	6,65	3,45	0,8	0	3,27	38,87	1,14
Bwy1	51,5	6,7	8,1	30,50	13,75	39,05	8,3	0	1,54	55,25	28,99
Bwy2	48,5	16,6	7,8	27,30	46,27	143,70	23,7	0	1,20	137,94	88,10
Bwy3	52,0	17,1	7,8	26,70	44,08	152,90	25,7	0	1,08	138,77	89,10
Bwy4	42,5	20,9	7,8	27,80	54,48	194,15	30,3	0	1,25	163,76	121,69

STOP 3: Sodic Haplogypsids developed in the glacis of the Land Unit "El Saso-Valdezurrones".

PEDON QE - 143

Reference coordinates on the orthophoto E5 412 10 04
x 703730 y 4586675 z= 225 m

Geomorphology

Landform: glacis
Slope: < 2%

Land use: Livestock

Vegetation: *Suaeda vera*

Described by: J.M. Salamero. 15/05/90

Classification: Sodic Haplogypsid, fine, gypsyc, thermic.

PROFILE DESCRIPTION (SINEDARES, CBDSA, 1983)

Ap1 0 - 10 cm
Dry; yellowish red (5 YR 5/8); without coarse fragments; silty clay loam; strong, medium subangular blocky structure; few organic matter; strong reaction to HCl (11%); clear and smooth boundary.

Ap2 10 - 30 cm
Dry; yellowish red (5 YR 5/8); without coarse fragments; silty clay; strong, very coarse angular blocky; few organic matter; strong reaction to HCl (11%); few (< 1%) vermiform gypsum accumulations and gypsum nodules; clear and smooth boundary.

Bwyz1 30-45/65 cm
Dry; yellowish red (5 YR 5/8); without coarse fragments; clay; primary structure: strong, coarse angular blocky; secondary structure: strong medium angular bloky with horizontal orientation; medium reaction to HCl (11%); bright faces of structural elements; frequent vermiform gysum accumulations, fine and soft, distributed all over the horizon; clear and wavy boundary.

Bwyz2 45/65 - 73 cm
Dry; yellowish red (5 YR 5/6); without coarse fragments; silty clay; strong, very coarse angular blocky structure; few infilled channels and coprolites; human activity: few charcoal fragments; medium reaction to HCl (11%); very frequent vermiform gypsum accumulations, medium and soft, distributed all over the horizon; gradual and smooth boundary.

Bwyz3 73 - 101 cm
Dry; yellowish red (5 YR 5/8); without coarse fragments; clay; weak, coarse angular blocky structure; medium reaction to HCl (11%); very frequent vermiform gypsum accumulations, medium and soft, distributed all over the horizon; gradual and smooth boundary.

Bwyzss4 101 - 155 cm
Slightly moist, yellowish red (5 YR 5/8); without coarse fragments; clay; strong, very coarse prismatic blocky structure; medium reaction to HCl (11%); few slickensides; bright surfaces associated to the faces of the structural elements; frequent medium size crystals and few vermiform gypsum accumulations, fine and soft, distributed all over the horizon; diffuse boundary.

Bwyzss5 155 - 200 cm ↓
Same as the previous upper horizon but with very strong angular blocky structure.

ANALYTICAL DATA

Horizon	Depth cm	pH H_2O 1:2,5	E.C. 1:5 dS/m at 25 °C	Calcium carbonate equivalent %	Gypsum equivalent %	Organic matter %
Ap1	0-10	8,0	2,1	18,5	<5	1,8
Ap2	10-30	8,0	3,5	17,4	<6	1,6
Bwyz1	30-40	8,1	4,6	20,5	9	1,2
Bwyz2	65-73	8,6	5,1	16,6	37	1,1
Bwyz3	73-101	8,4	4,5	9,4	39	1,7
Bwyzss4	101-155	8,5	5,1	13,6	14	1,9
Bwyzss5	155-200	8,5	5,1	13,6	14	1,9

		Granulometry USDA			
Horizon	Depth cm	Sand %	Silt %	Clay %	Classification
Ap1	0-10	5,20	59,72	35,05	SCL
Ap2	10-30	6,18	51,69	42,13	SC
Bwyz1	30-40	5,04	39,66	55,29	C
Bwyz2	40-55	16,76	38,31	44,92	C
	55-73	8,83	39,59	51,57	C
Bwyz3	73-87	21,69	34,21	44,08	C
	87-101	23,95	30,35	45,68	C
Bwyzss4	101-120	8,33	39,36	52,30	C
	120-140	11,17	34,98	53,83	C
Bwyzss5	155-200	6,79	40,28	52,91	SC

				Saturated paste extract							
Horizon	Water %	E.C. dS/m	pH	Ca^{++} meq/L	Mg^{++} meq/L	Na^{+} meq/L	SAR	$CO_3^{=}$ meq/L	HCO_3^{-} meq/L	$SO_4^{=}$ meq/L	CL^{-} meq/L
Ap1	39,5	5,8	8,0	40,3	9,2	21,3	4,3	0	4,4	35,6	28,4
Ap2	42,5	12,7	8,0	40,2	19,4	104,8	19,2	0	2,4	60,3	85,6
Bwyz1	51,0	17,4	7,9	36,7	28,8	163,9	28,7	0	1,3	93,5	134,5
Bwyz2	50,0	21,5	8,2	28,5	29,3	244,8	45,6	0	1,2	166,0	135,4
Bwyzss3	38,0	19,5	8,1	29,6	29,4	267,5	49,2	0	1,0	201,6	124,1
Bwyzss4	53,5	19,4	8,1	27,9	29,7	213,4	39,8	0	0,8	156,2	114,0

STOP 4: Typic Haplogypsids developed in the platform of the Land Unit "El Saso-Valdezurrones".

PEDON QE - 149

Reference coordinates on the orthophoto E5 413 01 05
x 708450 y 4583870 z= 240 m

Geomorphology

Landform: platform
Slope: > 2%

Land use: Agriculture. Cereal.

Described by: J.M. Salamero and O. Artieda. 28/06/91

Classification: Typic Haplogypsid, coarse silty, gypsic, thermic.

PROFILE DESCRIPTION (SINEDARES, CBDSA, 1983)

Ap 0 -20 cm
Slightly moist; yellowish red (5 YR 4/6); very abundant limestone coarse fragments from 2 to 25 cm in diameter, subangular-plane, randomly oriented, regulary distributed; silty clay loam; weak coarse angular blocky structure; firm; no aparent faunal activity; human activity: plough; rooting sistem limited by coarse material; abundant, very fine alive roots randomly oriented, regulary distributed; reaction to HCl (11%) very strong; accumulations: few (<1%) gypsum nodules; very abrupt and smooth boundary. Ochric.

2By(2Y) 25-52 cm
Moist; By(Y) horizon as intercalations between limestone strata. By(Y) horizon: clear grey (10 YR 8/2); silty loam; rooting sistem limited by coarse material; few alive and dead very fine roots, randomly oriented and concentrated along ped faces; reaction to HCl (11%) weak; diffuse and smooth boundary. Gypsic.

3R/ 4Cr 52-85 cm ↓
Lutite with limestones; no roots; medium reaction to HCl (11%).

ANALYTICAL DATA

Horizon	Depth cm	pH H_2O 1:2,5	E.C. 1:5 dS/m at 25 °C	Calcium carbonate equivalent %	Gypsum equivalent %	Organic matter %
Ap	0-20	7,7	2,44	43,6	15	2,0
2By (Y)	20-50	7,7	2,54	4,9	92	-
4Cr	50-85	7,7	2,53	47,3	40	-

Granulometry USDA

Horizon	Sand %	Silt %	Clay %	Clasificación
Ap	21,70	54,77	23,52	Silty loam

Saturated paste extract

Horizon	Hs %	E.C. dS/m	pH	Ca^{++} meq/L	Mg^{++} meq/L	Na^{+} meq/L	SAR	$CO_3^{=}$ meq/L	HCO_3^{-} meq/L	$SO_4^{=}$ meq/L	CL^{-} meq/L
Ap	41,6	4,0	7,6	18,8	3,7	17,3	5,2	0,0	2,0	20,4	17,4
2By (Y)	53,2	4,3	7,5	21,7	8,3	18,4	4,8	0,0	1,0	35,4	12,1

STOP 5: Torrifluvent developed on the lower terrace of the Ebro river, Huerta Land System.

Profile: QE-13

Location: Quintillo (Quinto, Zaragoza)
UTM x 710.620
y 4.589.790
Ref. Map: IGN 413

Parent material:
Fine terrigenous detritical material

Soil moisture regime: aridic

Geomorphology
Regional landform: Tabular relief
Local landform: simple slope, flat area, general slope: < 1%, local slope: < 1%.

Hydrology
Water table: not reached. Surface irrigation without drainages
Soil drainage class: Well drained

Vegetation and landuse
Agriculture: corn (*Zea mays*)

Stoniness None

Bedrock outcrops Absent

Classification: **Ustic Torrifluvent, fine-loamy, mixed (calcareous), thermic** (SSS, 1996)

PROFILE DESCRIPTION (SINEDARES)

Ap 0 - 40 cm
Dark brown (10YR 4/3). State of oxidation. Very few (< 1%) coarse fragments. Silty clay loam textural class. Strong structure, subangular blocky. Compact. Sticky. Friable. Very strong. Few (1-2%) organic matter. Few shell fragments (<1%). Few human activity: stubble burning. Abundant roots, medium size (2 - 5 mm diameter), vertical, regular distribution. Strong reaction to HCl (11%). Clear and smooth boundary.
Ochric epipedon.

Bw$_1$ 40-75 cm
Light yellowish brown (10YR 6/4). State of oxidation. Very few coarse fragments (< 1%). Silty clay loam textural class. Strong structure, angular blocky. Compact. Sticky. Friable. Fauna activity: abundant infilled galleries (5-20%) and frequent turricles (1-5%), few shell fragments (<1%). Human activity: Few ceramic fragments. Frequent fine roots (1-2 mm diameter). Strong reaction to HCl (11%). Few coatings (<10% afected surface), associated to pores and root channels, very thin (< 0,05 mm). Clear and smooth boundary.

Bw$_2$ 75-170 cm
Brownish yellow (10YR 6/6). State of oxidation. Very few coarse fragments (< 1%). Silt loam textural class. Moderate structure, angular blocky, coarse. Not very compact. Slightly sticky. Very friable. Few shell fragments. Few roots, very fine (<1mm). Strong reaction to HCl (11%). Clear and smooth boundary.

2C 170->240 cm
Sandy loam, coarser in depth. Structureless. Loose. Non sticky. Low faunal activity: galleries.

ANALYTICAL DATA

REFERENCE		HORIZON	Depth cm	pH H_2O 1:2.5	E.C. dS/m a 25°C 1:5	E.C. dS/m a 25°C 1:1	EQUIVALENT CALCIUM CARBONATE %	ORGANIC MATTER %
QE-13/1	8421	Ap	00-40	8.2	0.42	1.36	28.6	2.7
QE-13/2	8422	Bw_1	40-75	8.2	0.45	1.58	30.9	1.6
QE-13/3	8423	Bw_2	75-170	8.2	0.44	1.42	33.3	0.8
QE-13/4	8424	-	125	-	0.36		-	0.7

Coarse silt 0.050-0.020	Fine silt 0.020-0.002	SAND 2.000-0.500 (%)	SILT 0.500-0.50 (%)	CLAY <0.002 (%)	Classification (USDA)	WATER RETENTION	
						-33 kPa	-1500 kPa
14.4	32.5	21.4	46.9	31.6	CL	22.8	10,49
16.6	32.8	19.6	49.4	30.9	SCL	21.9	10,47
20.1	34.3	21.7	54.4	23.9	SL	21.8	7,90
-	-	-	-	-	-	-	-

Fertility		Saturated paste			
P ppm	K ppm	Percent water saturation	C.E. dS/m	pH	Cl^- meq/l
52.0	147.0	49.6	2.09	8.25	7.5
		48.0	2.48	8.21	9.2
		47.2	2.68	8.17	10.2
		46.3	2.36	8.14	11.7