HOW SOIL FORMING PROCESSES DETERMINE SOIL-BASED VITICULTURAL ZONING

J.M. Ubalde[1]*, X. Sort[1], and R.M. Poch[2]

[1]Department of Viticulture, Miguel Torres Winery, Miquel Torres i Carbó 6, 08720 Vilafranca del Penedès, Barcelona, Spain. [2]Department of Environment and Soil Science, University of Lleida, Rovira Roure 191, 25198 Lleida, Spain.
*Corresponding author: jmubalde@torres.es

ABSTRACT

The aim of this study was to elucidate the soil forming processes of representative vineyard soils, and to discuss the implications on a soil-based viticultural zoning at very detailed scale. The study area is located in Priorat, Penedès and Conca de Barberà viticultural areas (Catalonia, North-eastern Spain). The studied soils belong to representative soil map units determined at 1:5,000 scale, according to Soil Taxonomy classification. The soil forming processes, identified through morphological and micromorphological analyses, have significant effects on some soil properties. For example, the different processes of clay accumulation in soils developed from granodiorites in Priorat or gravel deposits in Conca de Barberà, are primarily responsible for significant differences in clay content, available water capacity and cation exchange capacity. These soils properties, especially those related to soil moisture regime, have a direct influence on vineyard management and grape quality. However, soil forming processes are not always reflected on soil classification, especially in soils modified by man. We show that climate or geology alone cannot be used in viticultural zoning at very detailed scale, unless soil forming processes are taken into account.

Keywords: soil formation, soil micromorphology, soil survey, soil classification.

INTRODUCTION

During recent years, viticultural zoning studies have increased significantly in relation to the expansion of the international wine market. Viticultural zoning can be defined as the spatial characterization of zones that produce grapes or wines of similar composition, while enabling operational decisions to be implemented (Vaudour, 2003). Among the various environmental factors and for a specific climate, soil is the most important factor on viticultural zoning, due to its direct effect on vine development and wine quality (Sotés and Gómez-Miguel, 2003). The soil properties which have the most influence are the physical ones, namely the properties that control the soil water content (Seguin, 1986), due to their direct effect on equilibrium between vegetative vigour and grape growing (Van Leeuwen and Seguin, 1994), and consequently on grape and wine quality (Esteban *et al.*, 2001; Trégoat *et al.*, 2002; Gurovich and Páez, 2004). In general, relationships between soil minerals and wine quality cannot be established (Seguin, 1986), except for nitrogen (Choné *et al*., 2001; Hilbert *et al*., 2003), unless severe deficiencies affecting vineyard growing occur (Van Leeuwen *et al*., 2004). For example, a calcium excess may be responsible of iron deficiencies (iron chlorosis), which can greatly affect grape production. However, some studies have shown an effect of soil cations on grapes and wine quality (Peña *et al*., 1999; Mackenzie and Christy, 2005). The physicochemical properties of soils are determined by the soil forming processes under which they form (Ritter, 2006). Some soil forming processes, such as clay accumulation or mineral weathering may have a great influence on soil physical properties, which are the most important for grapevine cultivation (Ubalde *et al*., 2007, 2009).

There are several approaches through soil studies which are oriented to viticultural zoning (Van Leeuwen *et al*., 2002), but the methods that provide more information are soil survey techniques, since they bring both the knowledge of spatial variability of soil properties and soil classification according to its viticultural potential (Van Leeuwen and Chery, 2001). Therefore, soil maps are usually used as the basic maps for zoning studies. In Dutt *et al*. (1981) distinct viticultural regions were determined by considering the soil temperature regime. Astruc *et al*. (1980) considered the water availability as the most important factor, followed by carbonates and other chemical components. Morlat *et al*. (1998) considered the effective soil depth as the main property, since this is directly related to water availability by the roots. Many viticultural zoning studies note the importance of water availability, since this property integrates edapho-climatic, biological and human factors (Duteau, 1981; Sotés and Gómez-Miguel, 1992; Van Leeuwen *et al*., 2002). Soil survey methods based on Soil Taxonomy classification (SSS, 1999) were useful for viticultural zoning studies at different detail levels (Gómez-Miguel and Sotés, 2001; Gómez-Miguel and Sotés, 2003, Ubalde *et al*., 2009). Soil forming processes, through their effects on edaphic properties and their implications on Soil Taxonomy, may have a great importance on a viticultural zoning based on soil surveys. However, as mentioned above, many viticultural zoning studies are based on the relationships between grape and wine quality and certain soil properties or different soil forming factors, namely climate (Coombe, 1987; Hamilton, 1989), geology (Van Schoor, 2001) and topography (Dumas *et al*., 1997), but there are no studies that consider possible relationships with soil forming processes.

In this study, representative soils of a very detailed soil survey, which was carried out for viticultural zoning purposes, were selected. The study area is composed of high quality producing vineyards of Catalonia, namely the viticultural regions of Priorat, Conca de Barberà and Penedès. The relationship between soils and grape and wine quality in the study area is discussed elsewhere (Andrés-de-Prado *et al*., 2007, Ubalde *et al*., 2007, 2009). In this paper we want to analyze whether the soil forming processes, through their effects on soil properties and classification, deserve to be considered in a viticultural zoning based on soil surveys. At our knowledge, this approach has never been addressed before. In short, the aim of this study was to elucidate the soil forming processes of representative vineyard soils, and discuss about the implications on soil classification and viticultural zoning.

MATERIALS AND METHODS

The study area is high quality producing vineyards, located in different protected viticultural areas of Catalonia: Conca de Barberà, Priorat and Penedès. The area is enclosed approximately between 41º 3’ N and 41º 48’ N and between 0º 40’ E and 1º 53’ E. The altitude ranges approximately between 220 m and 550 m. The study area has an old viticultural history, which started in some cases during the 4th century BC. Since the 1980s - 1990s, the systems of grapevine cultivation have evolved to highly mechanized farms, which seek to obtain maximum profitability but maintaining high quality products. Thus, a widespread practice was the removal of old stone walls, in order to obtain larger plots. In these cases, land levelling usually involved a change in the arrangement of soil horizons, sometimes leading to a decline of soil fertility.

The vineyards are situated on the Catalan Coastal Range and the Ebro Basin. The Catalan Coastal Range is an alpine folding chain formed by both massifs and tectonic trenches (Anadón *et al*., 1979). The Conca de Barberà soils are located in the footslope of the massif, named ‘Serra de Prades’ in this region. The soils are developed from gravel deposits of different ages, which are composed of siliceous Paleozoic materials (Silurian and Carboniferous slates and granites) (IGME, 1975a). The Priorat soils are located in the hillslope of the Priorat Massif, which is composed of Carboniferous slates and granodiorites (IGME, 1978). The slates are named ‘llicorella’ in this region, and they are considered the main responsible for grape quality. The selected Penedès soils are located in 2 subdivisions, which can be called Upper Penedès and Middle Penedès. The Middle Penedès soils are located in a tectonic trench named Penedès Basin, where calcareous Miocene materials (marls, conglomerates, limes) outcrop (IGME, 1982). The Upper Penedès soils are located in the Ebro basin margin, next to the Alt Gaià Massif. Calcareous materials from Oligocene and Eocene predominate in this region (IGME, 1975b).

The climate type is Mediterranean, characterized by a warm, dry summer, even though there are differences in temperatures and precipitation according to the altitude and distance to the sea. The mean annual precipitation ranges from 520 mm in Penedès to 589 mm in Priorat, showing seasonal variations (Fig. 1). In all regions, the precipitation has a bimodal distribution (peaks in spring and autumn) and a minimum of precipitation in summer, particularly in July. The highest temperatures occur in summer, particularly in July or August, while the lowest temperatures occur in winter (January). Comparing different regions, the warmest one is Penedès, with an average annual temperature of 14.9 ºC, and the cooler one is Priorat, with an average annual temperature of 12.7 ºC. The soil moisture regime is xeric and the soil temperature regime is mesic (Priorat and Conca de Barberà) or thermic (Penedès) (SSS, 1999).

The studied soils belong to soil map units determined according to the Soil Survey Manual of the Department of Agriculture of United States (SSS, 1993), at very detailed scale (1:5,000). Soil map units were delineated as polygons from soil observations, which were selected according to different landforms and lithologies. The density of soil observations was 1 observation by cm^2 of map, of which a sixth part corresponded to soil pits and the rest to soil auger holes. The depth of soil profiles was the shallowest of a root-limiting layer or 200 cm. When applying a ratio of soil pit: soil

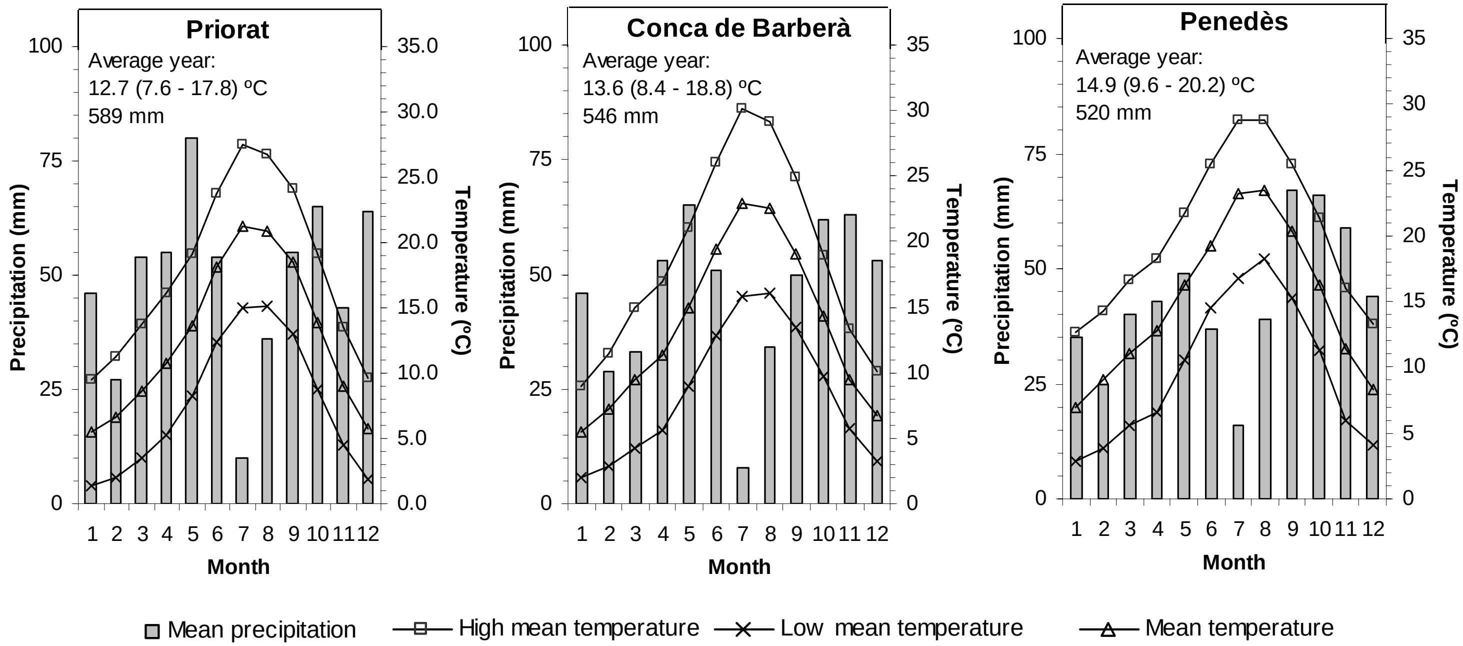

Figure 1. Average climatic data of the viticultural areas of Priorat, Conca de Barberà and Penedès.

auger hole 1:5, 0.7 soil pits by hectare were dug. For each profile, a detailed field description included site description (location, soil temperature and moisture regime, drainage class, depth to water table, geomorphic information, parent material and surface stoniness) and profile description (horizon depth and genetic denomination (SSS, 1999), soil colour (Munsell charts), mottles, coarse fragments, structure, consistence, cementations, effervescence (hydrochloric acid), roots, pores, cracks, biological and human activity, accumulation of materials and ped and void surface features) (CBDSA, 1983; Schoeneberger *et al*., 2002; Porta and López-Acevedo, 2005). Moreover, for each horizon, physical and chemical properties were analysed, according to the Soil Survey Laboratory Methods Manual of the Department of Agriculture of United States (USDA, 1996). The selected physical properties were texture (pipette method) and moistures at -33 KPa and -1500 KPa (pressure-plate extraction from disturbed samples). The selected chemical properties were pH (suspension of 1:2.5 soil:water), electrical conductivity (suspension of 1:5 soil:water), organic matter (Walkley-Black), calcium carbonate (Bernard calcimeter), gypsum (extracted by acetone), cation exchange capacity and exchangeable bases (extracted by ammonium acetate).

In some cases, a micromorphological study was undertaken in order to clarify or identify pedogenic processes which were difficult to detect with the naked eye. For the micromorphological study, thin sections were elaborated from undisturbed soil material according to Benyarku and Stoops (2005). Samples were taken of deep horizons, since surface horizons were disturbed by ploughing. One to two samples were collected for each selected profile. We described a total of 23 thin sections from 19 soil profiles and 8 soil map units. The criteria of Stoops (2003) were used in thin section description.

When soil profiles were fully characterized, they were classified according to Soil Taxonomy (SSS, 2006) at series level. Each series consists of soil layers that are similar in colour, texture, structure, pH, consistence, mineral and chemical composition, and arrangement in the profile. In the study area every 3 to 4 soil profiles belonged to one soil series, by average.

The soil series were used to delineate the soil map units (SMU), following the criteria of Van Wambeke and Forbes (1986). The soil survey party plotted the map unit boundaries onto orthophotographs. These boundaries were determined by means of soil observations, looking for differences in slope gradient, landform, colour and stoniness. When all SMU were delineated, they were listed and codified and the soil map legend could be designed. The final number of SMU was approximately twice the number of soil series. The mean surface of the delineated SMU was 1.4 hectares.

Significant differences among soil series were analysed by ANOVA, considering the analytical properties of soil series as dependent variables and soil series as categorical factors. This analysis was done for each horizon separately. Means were separated by Newman-Keuls post-hoc analysis ($p < 0.05$). The software used was STATISTICA (StatSoft, Inc.).

RESULTS AND DISCUSSION

In this study, a wide range of soil forming processes was identified in vineyard soils of Catalonia, which is reflected in their classification. The studied soils belong to Entisol, Inceptisol and Alfisol orders (SSS, 2006), according to a wide variety of soil forming processes and their resulting diagnostic horizons and characteristics (Table 1). Entisols are characterized by little or no evidence of soil formation, so that any diagnostic horizons are not developed, except to an ochric epipedon. Within that order, the suborders found are Orthents, Fluvents, Psamments and Arents. Orthents are formed on recent erosional surfaces, and most of them are shallow soils with a root-limiting layer (lithic or paralithic contact). Fluvents are formed in alluvial and colluvial parent materials, and are characterized by being deep soils, which are rich in organic matter in depth. Psamments are characterized by being sandy. Arents are anthropogenic soils, deeply mixed by methods of moving by humans. Arents should present fragments of diagnostic horizons not arranged in any discernible order. With regard to Inceptisols, these soils are characterized by being in early stages of soil formation. These soils could undergo distinct accumulation processes of carbonates and gypsum or simply evidences of physicochemical transformations or removals. Soils with well-developed carbonate accumulations (calcic horizon) or cementations (petrocalcic horizon) are classified as Calcixerepts and soils with gypsum accumulations (gypsic horizon) are classified as Gypsic Haploxerepts. The Haploxerept group is also used when accumulations processes are too incipient to form calcic or gypsic horizons, or when a change of colour occurs. In this case, the diagnostic horizon described is cambic. Finally, Alfisols are characterized by silicate clay illuviation (argillic horizon). In the study area, these soils could present carbonate accumulations (calcic horizon), covering clay accumulations.

The presence of carbonates in parent material determines the carbonate accumulation processes identified in Penedès area, much more intense than those of Priorat and Conca de Barberà. Calcium carbonate accumulations in soils are possible thanks to a Mediterranean climate, which are responsible of seasonal soil water deficits. However, some processes, such as clay illuviation in calcareous soils, can only be explained by a wetter relict climate, which would allow a substantial base leaching and a slight acidification. The time effect can be observed in Conca de Barberà soils, which are developed from colluvial deposits of different ages but same origin (IGME, 1975a). In modern colluvial deposits, the most developed soil forming process is in situ clay neoformation. However, a process of clay illuviation and then a process of secondary carbonate accumulation could take place in the old colluvial deposits. Obviously, the variations in climate over time had strongly influenced these processes. Regarding the relief factor, Priorat soils on hillslopes or Penedès soils on valley bottoms were more exposed to processes of soil rejuvenation than Conca de Barberà soils on more stable positions. The main effects of biological activity are related to bioturbation. However, biogenic carbonate accumulations are described in Penedès region. Finally, human activity has a strong influence on the formation of some soils of the study area. The most aggressive activities are related to land levelling and terracing. Soil tillage and the application of fertilizers and manures also affect surface horizons.

Soil forming processes in Priorat

The selected Priorat soils are developed in the Priorat Massif, which is composed mainly of Paleozoic slates, which are intruded by granodiorite veins in some areas. Generally, these soils are poorly developed, that is, they show little evidence of soil formation. This is because these soils are formed on recent

Table 1. Classification and main characteristics of vineyard soils in the Catalan Coastal Range.

Order	**Suborder**	**Group**	**Subgroups**	**Diagnostic horizons**	**Main characteristics**	**Correspondence WRB (2006)**
Entisols	Orthents	Xerorthents	Typic	Ochric	Paralithic contact	Regosols
			Lithic	Ochric	Lithic contact	Leptosols
	Fluvents	Xerofluvents	Typic	Ochric	High content of organic carbon in deep horizons	Fluvisols
	Psamments	Xeropsamments	Typic	Ochric	Texture coarser than sandy loam	Arenosols
	Arents	Xerarents	Alfic	Ochric, fragments of argillic	Diagnostic horizons not arranged in any discernible order	Anthrosols
Inceptisols	Xerepts	Haploxerepts	Typic	Ochric, cambic	Evidences of the removal of carbonates or rubefaction	Cambisols
			Fluventic	Ochric, cambic	Rubefaction and high content of organic carbon in deep horizons	Cambisols
			Gypsic	Ochric, gypsic	Significant secondary gypsum accumulations	Gypsisols
		Calcixerepts	Typic	Ochric, calcic	Significant secondary carbonate accumulations	Calcisols
			Petrocalcic	Ochric, petrocalcic	Horizons indurated by secondary carbonates	Calcisols
Alfisols	Xeralfs	Palexeralfs	Calcic	Ochric, argillic, calcic	Evidence of clay illuviation and significant secondary carbonate accumulations	Luvisols

erosional surfaces (hillslopes), with shallow parent materials, which are greatly affecting soil properties. Moreover, the properties of the parent materials are not particularly favourable for the development of soil structure. Slates are highly exfoliated, favouring high rock fragment contents, and the weathering product of granodiorites is granitic sands, named ‘sauló’ in the study area, which greatly hinder the aggregation of particles (soil structure formation).

As mentioned above, soils developed from granodiorites are characterized by being shallow and with very high sand content, with regard to the parent material composition. The parent material is a granitic regolith up to 2-5 m, which is a product of in situ alteration of the granodiorite, and it corresponds to a sandstone formation with a small proportion of clay and silt (IGME, 1978). This sandstone could be broken up with a shovel, but it is too compact to permit root development. The parent material is composed of eye-visible crystals of quartz, feldspar (plagioclase and orthose) and mica (biotite) (Fig. 2). These minerals are generally unaltered, but locally some biotite crystals are transformed to chlorite and vermiculite. Generally, this regolith is light-coloured, but in some cases is strongly rubefacted. This red colour is related to clay accumulations, whose origin is mainly biotite alteration, which resulted in pseudomorphic units of oriented clay (Fig. 3). However, some clay could have an illuvial origin, as suggested by McKeague (1983) in similar soils. The clay pedofeatures are pure microlaminated coatings on sand grains (0.05 - 0.1 mm width).

On the other hand, soils developed from slates are shallow and with high rock fragment contents, representing a strong limitation to root development. However, the parent material, composed of iron and magnesium silicates, present a planar exfoliation that roots can use for their development. In addition, clay accumulation processes are found in some cracks, creating intercalations of clayey material in the rock (Fig. 4). These intercalations could suppose until 15% in total slate volume. The described pedofeatures are coatings and infillings of clay in pores and cracks of coarse components. In all these types of accumulations, clay is pure, that is, it does not present other particles sizes (silt). Accumulations show a microlaminated internal contexture, sometimes hard to see. The origin of clay is probably illuvial, as it meets the characteristics of an ideal argillic horizon (McKeague, 1983): continuous coatings on both sides of the pores, strongly oriented, with microlamination, without sand grains and clearly different from the matrix which does not contain any fragment of oriented clay.

In all soils, redoximorphic mottles of iron and manganese are described related to clay accumulations. The pedofeatures are impregnative nodules, associated to pores and coarse components. These nodules are dark, with a gradual boundary, an irregular shape and a diameter between 0.1 and 0.4 mm. These nodules indicate an incipient hydromorphy, caused by perched water tables, of limited influence area, which would be possible thanks to high clay content.

The Priorat soils are classified as Entisols, since the soil forming processes are not enough developed to determine any diagnostic horizon, except to an ochric epipedon. In general, soils developed from granodiorites are classified as Xeropsamments, which are characterized by a texture coarser than loamy fine sand and less than 35 % of rock fragments (Table 2). However, soils developed from rubefacted granitic regolith, are classified as Typic

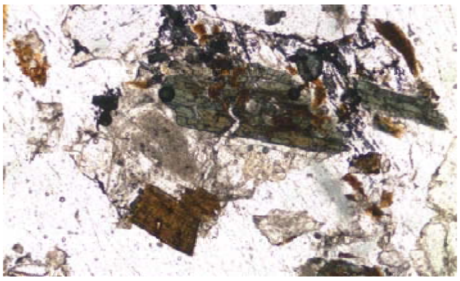

Figure 2. Mineral composition of granitic regolith (quartz in pure white, feldspars in impure white, mica in dark), with mica alteration in the centre of the picture (3.36 mm width, PPL).

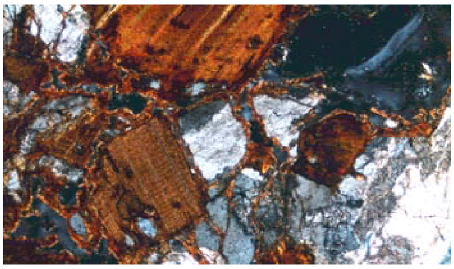

Figure 3. *In situ* clay neoformation in rubefacted granitic regolith: micro-laminated coatings on sand grains (3.36 mm width, XPL).

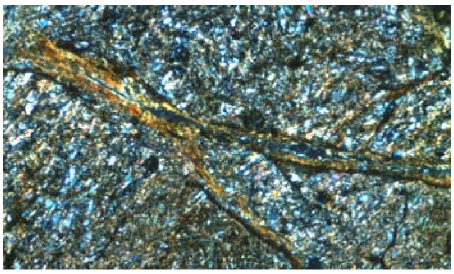

Figure 4. Clay illuviation in slates: clay infillings in cracks and clay coatings in pores (1.68 mm width, XPL).

Xerorthents. These soils cannot be classified as Alfisols, since evidences of illuvial clay is required for an argillic horizon, and in this case, the clay origin is biotite alteration. Moreover, these soils cannot be classified as Inceptisols because the deep horizons maintain the rock structure, and consequently the criteria for cambic horizon are not accomplished. With respect to soils developed from slates, they are classified as Lithic Xerorthents, in spite of presenting an exfoliated rock with intercalations of material enriched in illuvial clay. There is a subgroup in the Alfisols, named Lithic ruptic-inceptic Haploxeralfs, which is defined by presenting a lithic contact and an argillic horizon discontinuous horizontally. However, in the studied soils, the thickness of material with illuvial clay is generally lower than 7.5 cm, so the criteria for argillic horizon are not accomplished.

In Priorat soils, the clay formation supposes an improvement of the soil water reservoir for the vineyard, a fact which is especially important in a stressful environment, related to a Mediterranean climate with a dry, warm growing season, soil shallowness and high content of gravels or sands, which confer very quick internal soil drainage. In soils developed from slates, the available water capacity (AWC) of plough horizons is moderate (42.4 mm between 0 and 45 cm depth), so the water retained by the clay-rich materials among the rock cracks is worth considering (23.3 mm between 45 and 138 cm depth) (Table 2). Moreover, the presence of redoximorphic features related to clay features would indicate that clay accumulation is causing an alteration in the soil moisture regime. In soils formed from granodiorites, processes with major implications for grapevine cultivation are also identified. These soils, in addition to shallowness, are composed practically by sand (Table 2), so that there are not particles of silt or clay to retain water. As a result, these soils produce a higher water stress than soils formed from slates, because they have a very low AWC (12.4 mm between 0 and 42 cm depth). The existence of rubefacted granodiorites with neoformed clay (Typic Xerorthents) result in soils with finer textures, with a significant increase of the AWC (45.8 mm between 0 and 37 cm depth) in comparison with the non-rubified Xeropsamment. Another soil property improved with clay accumulations is the cation exchange capacity (CEC) of surface and deep horizons. In surface horizons, CEC significantly increases from 4.4 to 9.9 $cmol_c/kg$. This increase represents a substantial improvement of nutrient availability for the vine and the possibilities of development of soil structure and stability of soil aggregates, which is especially important in these soils that are poor in organic matter (contents lower than 0.5%). In short, clay accumulations significantly improve the AWC and CEC, although not always involve major changes in soil classification.

Soil forming processes in Penedès

The Penedès soils differ from the soils in the other areas by their parent materials which are richer in calcium carbonate, so that carbonate-related soil forming processes are better represented. Much of the carbonate accumulations are due to the precipitation of calcite from saturated solutions, which is leached from upper horizons or from lateral water flow caused by an impervious horizon. However, some carbonate accumulations come from biological activity, which cause a carbonate microdistribution around biopores (Boixadera *et al*., 2000). The features of biological accumulations are infillings of citomorphic calcite (quesparite) in pores (Fig. 5). The features of carbonate illuviation are representative of different degrees of calcification. First, a process of crystallization produces acicular crystals and few hypocoatings of micrite and microsparite (Fig. 6). Then, a process of recrystallization produces abundant coatings and well-developed hypocoatings, pendants, nodules and infillings of sparite and microsparite (Fig. 7). Later, carbonates (micrite) begin to occupy the micromass. In this stage, processes of displacement and replacement of grains or clay coatings by carbonates can occur. The most evolved stage corresponds to carbonate cementation (petrocalcic horizons).

Besides carbonate accumulation, processes of gypsum accumulation are found in the Upper Penedès soils. The gypsum-related features are coatings of lenticular crystals. In addition, mixed silt and clay hypocoatings around pores and coarse components are common in clayey soils. These features correspond to whole-soil hypocoatings (Fitzpatrick, 1990; 1993), originated by the downward flow of a suspension of fine material, which may disperse after a single rain. It is a characteristic feature of clayey, continuously cultivated soils, which loose their structure, crack and form wide planar vertical pores.

Most of the Penedès soils are classified as Inceptisols, because carbonate or gypsum accumulations are enough expressed to identify calcic, petrocalcic or gypsic horizons. Generally, they are classified as Typic Calcixerepts, Petrocalcic Calcixerepts and Gypsic Haploxerepts, respectively. However, not all soils with carbonate accumulations can be classified as Calcixerepts, since they do not meet the criteria for a calcic horizon. A calcic horizon requires a minimum thickness of 15 cm, a minimum

Table 2. Analytical properties of representative vineyard soils in Priorat region a.

Properties	Horizon	Sandy, mixed, mesic, shallow, Typic Xeropsamments	Loamy, mixed, active, mesic, shallow, Typic Xerorthents	Loamy-skeletal, mixed, semiactive, mesic, Lythic Xerorthents
Soil Forming Processes		Mineral weathering, incipient mica alteration	Clay neoformation and rubefaction, generalized clay coatings on sand grains	Clay illuviation, clay coatin limited on rock cracks
Genetic horizon (SSS, 2006)	**1**	Ap_1	Ap_1	Ap_1
	2	Ap_2	Ap_2	Ap_2
	3	C	C	R/Bt (15% volume)
Lower depth (cm)	**1**	22.8 (1.18) a	14.5 (0.50) b	20.4 (2.06) ns
	2	42.1 (3.06) ns	37.0 (3.00) ns	45.0 (1.83) ns
	3	123.7 (8.85) ns	140.0 (10.00) ns	138.3 (18.90) ns
Munsell Colour	**1**	10YR5/4	5YR4/5	10YR4/4
	2	10YR5/5	5YR4/6	10YR4/4
	3	10YR5/6	5YR5/7	2.5Y5/4
pH (H_2O 1:2.5)	**1**	8.4 (0.07) a	8.4 (0.05) a	7.4 (0.19) b
	2	8.3 (0.11) a	8.4 (0.05) a	7.3 (0.17) b
	3	8.4 (0.08) a	8.4 (0.25) a	7.1 (0.31) b
Electrical Conductivity (dS/m)	**1**	0.20 (0.03) ns	0.16 (0.02) ns	0.41 (0.16) ns
	2	0.23 (0.03) ns	0.15 (0.01) ns	0.26 (0.04) ns
	3	0.21 (0.03) ns	0.23 (0.05) ns	0.38 (0.14) ns

[a] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

Continued.....

Properties	Horizon	Sandy, mixed, mesic, shallow, Typic Xeropsamments	Loamy, mixed, active, mesic, shallow, Typic Xerorthents	Loamy-skeletal, mixed, semiactive, mesic, Lythic Xerorthents
Soil Forming Processes		Mineral weathering, incipient mica alteration	Clay neoformation and rubefaction, generalized clay coatings on sand grains	Clay illuviation, clay coatings limited on rock cracks
Organic matter (%)	**1**	0.1 (0.03) ns	0.4 (0.10) ns	1.6 (0.99) ns
	2	0.3 (0.07) b	0.2 (0.10) b	1.4 (0.27) a
	3	trace	trace	trace
$CaCO_3$ (%)	**1**	trace	trace	trace
	2	trace	trace	trace
	3	trace	trace	trace
Cation Exchange Capacity ($cmol_c$/kg)	**1**	4.4 (1.02) b	9.9 (0.80) a	12.7 (0.46) a
	2	5.3 (0.13) c	9.0 (0.20) b	12.0 (0.80) a
	3	5.3 (0.65) b	8.9 (0.28) b	15.0 (0.00) a
Sand (%)	**1**	92.1 (0.64) a	62.9 (8.85) b	70.4 (2.98) b
	2	91.0 (0.52) a	72.1 (6.50) b	73.0 (4.54) b
	3	94.8 (0.51) a	89.4 (3.50) a	53.6 (0.00) b
Silt (%)	**1**	5.6 (0.46) b	22.3 (6.35) a	19.5 (3.24) a
	2	6.8 (0.45) b	16.4 (3.75) a	18.4 (3.87) a
	3	4.2 (0.32) b	7.4 (1.25) b	27.8 (0.00) a

[a] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

Continued…..

Properties	**Horizon**	**Sandy, mixed, mesic, shallow, Typic Xeropsamments**	**Loamy, mixed, active, mesic, shallow, Typic Xerorthents**	**Loamy-skeletal, mixed, semiactive, mesic, Lythic Xerorthents**
Soil Forming Processes		Mineral weathering, incipient mica alteration	Clay neoformation and rubefaction, generalized clay coatings on sand grains	Clay illuviation, clay coatings limited on rock cracks
Clay (%)	**1**	2.4 (0.56) b	14.9 (2.50) a	10.1 (0.42) a
	2	2.2 (0.50) b	11.6 (2.75) a	8.6 (1.15) a
	3	1.0 (0.41) b	3.3 (2.25) b	18.6 (0.00) a
Textural class (SSS, 2006)	**1**	Sand	Sandy loam	Sandy loam
	2	Sand	Loamy sand	Sandy loam
	3	Sand	Loamy sand	Sandy loam
Bulk density (kg/m^3)	**1**	1507.9 (10.25) b	1373.5 (10.42) b	1764.3 (97.75) a
	2	1545.1 (32.46) b	1665.9 (27.93) b	1931.0 (89.51) a
	3	1963.6 (16.42) a	1888.0 (0.74) b	1918.2 (20.86) ns
Coarse fragments (%)	**1**	trace	trace	53.3 (2.90)
	2	trace	trace	59.3 (2.73)
	3	-	-	22.0 (4.00)
Water retention at 1/3-bar (%)	**1**	4.7 (0.33) b	16.0 (1.00) a	21.4 (1.75) a
	2	5.7 (0.67) b	14.2 (2.00) a	18.3 (2.25) a
	3	-	-	22.0 (1.50)
Water retention at 15-bar (%)	**1**	3.2 (0.00) b	7.5 (0.50) a	8.0 (0.73) a
	2	3.3 (0.33) b	6.5 (0.50) a	8.0 (0.89) a
	3	-	-	11.0 (2.50)
Available Water Capacity (mm/10 cm)	**1**	2.3 (0.02) b	11.7 (0.09) a	11.0 (0.31) a
	2	3.7 (0.08) c	12.8 (0.22) a	8.1 (0.49) b
	3	-	-	2.5 (0.35)

[a] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

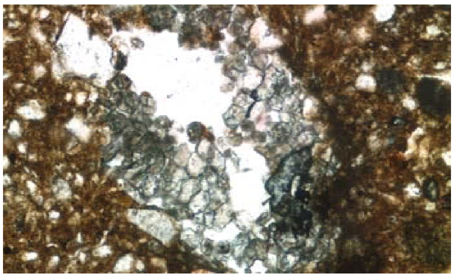

Figure 5. Biological carbonate accumulation in Typic Xerofluvents: pore infillings of citomorphic calcite. (3.36 mm width, PPL).

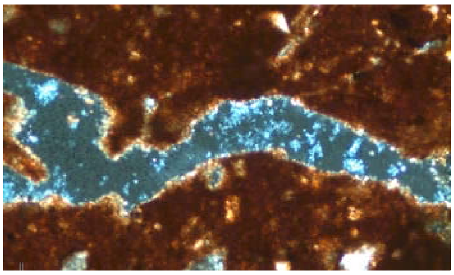

Figure 6. Carbonate redistribution in Typic Xerofluvents: acicular crystals infillings and microsparite hypocoating. (1.26 mm width, XPL).

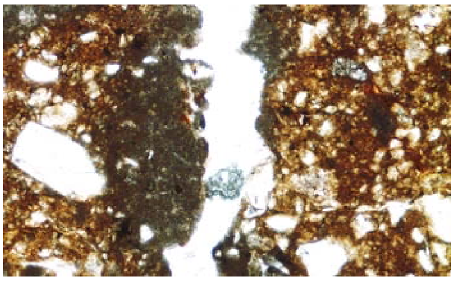

Figure 7. Carbonate redistribution in Typic Calcixerepts: well-developed microsparite hypocoating. (3.36 mm width, PPL).

$CaCO_3$ content of 15 % and identifiable secondary calcium carbonate, with some exceptions. Some described soils show incipient accumulations or present too low $CaCO_3$ content. Generally, these accumulations lead to cambic horizons, and soils are classified as Typic Haploxerepts. Even in some cases, where carbonate accumulations are not visible to the naked eye, a cambic horizon cannot be determined, and soils are classified as Entisols. Moreover, accumulations of mixed silt and clay (whole-soil hypocoatings) do not have any connotation in soil classification. Table 3 shows the analytical properties of a soil with a well-developed calcic horizon (Typic Calcixerept), a soil with incipient accumulations of carbonates and accumulations of mixed silt and clay (Typic Xerofluvent), as well as a soil with a gypsic horizon (Gypsic Haploxerept).

The soil forming processes in Penedès are marked by the accumulation of secondary carbonates, which can be highly evolved, as it is indicate by the types of accumulations and their morphology. This evolution is reflected with the calcium carbonate content, with mean values near 60 % (Table 3), and with carbonate cementations. The evolution of carbonates in these soils may be a limiting factor for grapevine cultivation. High contents in calcium carbonate can cause a weakening in non-resistant vines, due to iron chlorosis. The carbonates increase the concentration of the HCO_3^- anion in the soil solution, and this blocks the absorption of iron by plants. The main consequences are the rickets, the foliage destruction, a reduced production and even the death of the plant. These problems may be mitigated by the choice of resistant rootstocks, such as 41B and 140R. Furthermore, very

Table 3. Analytical properties of representative vineyard soils in Penedès region [b].

Properties	Horizon	Fine, mixed, semiactive, thermic, Typic Xerofluvents	Coarse-loamy, carbonatic, thermic, Typic Calcixerepts	Coarse-loamy, mixed, active, thermic, Gypsic Haploxerepts
Soil Forming Processes		Incipient carbonate accumulations: microscopic nodules, infillings and hypocoatings. Silt and clay accumulations.	Well-developed carbonate accumulations: macroscopic coatings on pores, geopetal cement and nodules; slight cementation.	Gypsum accumulations, crystals and coatings on pores.
Genetic horizon (SSS, 2006)	**1**	Ap_1	Ap_1	Ap_1
	2	Ap_2	Ap_2	Ap_2
	3	Bw	Bkn	By
Lower depth (cm)	**1**	13.0 (1.00) ns	17.0 (1.91) ns	13.3 (3.33) ns
	2	41.7 (1.67) ns	49.7 (4.63) ns	40.3 (1.45) ns
	3	98.3 (1.67) ns	99.2 (13.31) ns	78.3 (9.28) ns
pH (H_2O 1:2.5)	**1**	8.2 (0.09) a	8.5 (0.09) a	7.9 (0.00) b
	2	8.3 (0.10) a	8.5 (0.06) a	7.9 (0.00) b
	3	8.2 (0.15) ns	8.4 (0.05) a	8.0 (0.06) b
Electrical Conductivity (dS/m)	**1**	0.19 (0.01) b	0.19 (0.01) b	2.29 (0.01) a
	2	0.20 (0.03) b	0.21 (0.02) b	2.42 (0.08) a
	3	0.37 (0.15) b	0.32 (0.06) b	2.39 (0.04) a
Organic matter (%)	**1**	1.6 (0.17) ns	1.4 (0.12) ns	1.5 (0.13) ns
	2	1.2 (0.12) ns	1.1 (0.20) ns	1.2 (0.15) ns
	3	1.0 (0.23) ns	0.8 (0.16) ns	0.4 (0.10) ns

[b] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

Continued…..

Properties	Horizon	Fine, mixed, semiactive, thermic, Typic Xerofluvents	Coarse-loamy, carbonatic, thermic, Typic Calcixerepts	Coarse-loamy, mixed, active, thermic, Gypsic Haploxerepts
Soil Forming Processes		Incipient carbonate accumulations: microscopic nodules, infillings and hypocoatings. Silt and clay accumulations.	Well-developed carbonate accumulations: macroscopic coatings on pores, geopetal cement and nodules; slight cementation.	Gypsum accumulations, crystals and coatings on pores.
$CaCO_3$ (%)	**1**	33.0 (3.01) b	55.5 (8.41) a	26.3 (2.40) b
	2	35.7 (3.18) b	57.7 (9.96) a	25.0 (2.52) b
	3	28.3 (7.62) b	56.8 (6.54) a	22.0 (6.81) b
Gypsum (%)	**1**	trace	trace	32.7 (3.53)
	2	trace	trace	34.3 (3.53)
	3	trace	trace	44.0 (5.51)
Cation Exchange Capacity ($cmol_c$/kg)	**1**	14.0 (1.76) a	6.5 (1.06) b	10.9 (0.65) ns
	2	13.3 (1.82) a	6.4 (1.03) b	10.0 (0.75)ns
	3	16.5 (0.94) a	5.1 (0.58) b	7.8 (0.25) b
Sand (%)	**1**	31.9 (6.87) b	51.8 (3.82) a	42.2 (3.03) ns
	2	30.9 (7.75) b	50.1 (3.46) a	42.0 (1.91) ns
	3	19.3 (4.99) b	54.0 (4.83) a	59.5 (11.45) a
Silt (%)	**1**	35.4 (2.84) b	33.7 (2.67) b	50.5 (3.77) a
	2	38.6 (3.69) b	33.9 (2.19) b	53.2 (3.23) a
	3	36.2 (7.61) ns	31.5 (3.42) ns	34.3 (11.70) ns
Clay (%)	**1**	32.7 (4.43) a	14.5 (1.42) b	7.2 (0.91) b
	2	30.5 (5.50) a	16.1 (1.60) b	4.8 (1.32) c
	3	44.5 (4.42) a	14.5 (1.94) b	6.3 (0.25) b

[b] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

Continued…..

Properties	Horizon	Fine, mixed, semiactive, thermic, Typic Xerofluvents	Coarse-loamy, carbonatic, thermic, Typic Calcixerepts	Coarse-loamy, mixed, active, thermic, Gypsic Haploxerepts
Soil Forming Processes		Incipient carbonate accumulations: microscopic nodules, infillings and hypocoatings. Silt and clay accumulations.	Well-developed carbonate accumulations: macroscopic coatings on pores, geopetal cement and nodules; slight cementation.	Gypsum accumulations, crystals and coatings on pores.
Textural class (SSS, 2006)	**1**	Silty clay	Sandy loam	Silty loam
	2	Silty clay	Sandy loam	Silty loam
	3	Silty clay	Sandy loam	Sandy loam
Bulk density (kg/m^3)	**1**	1488.0 (120.00) ns	1383.8 (73.26) ns	1481.0 (42.00) ns
	2	1802.0 (29.00) ns	1517.3 (114.19)ns	1869.0 (46.00) ns
	3	1766.0 (12.00) ns	1502.5 (62.98) ns	1735.0 (40.00) ns
Coarse fragments (%)	**1**	trace	14.3 (10.65)	trace
	2	trace	12.0 (8.55)	trace
	3	trace	28.0 (7.40)	trace
Water retention at 1/3-bar (%)	**1**	23.3 (1.86) a	14.8 (0.75) b	26.7 (0.88) a
	2	23.0 (2.08) a	15.8 (0.95) b	26.7 (0.33) a
	3	26.7 (0.88) a	13.3 (1.65) c	22.0 (1.00) b
Water retention at 15-bar (%)	**1**	12.0 (1.53) a	6.0 (0.41) b	13.3 (0.67) a
	2	12.3 (1.45) b	7.0 (0.58) c	15.3 (0.33) a
	3	15.0 (0.58) a	5.8 (0.63) b	13.3 (0.67) a
Available Water Capacity (mm/10 cm)	**1**	15.0 (1.40) ns	10.5 (1.84) ns	19.3 (0.55) ns
	2	18.7 (2.58) ns	11.8 (1.89) ns	21.5 (1.46) ns
	3	20.7 (1.16) a	8.1 (1.82) b	14.8 (1.21) ns

[b] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p<0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

intense processes of carbonate accumulation, which leads to a micromass cementation, may constitute a limitation for the development of the root system. Moreover, carbonate accumulations in the form of nodules increase the coarse fragment content, and thus reduce the available water capacity (AWC). In deep horizons of a Typic Calcixerept, a loss of 11 mm of AWC can be quantified (between 50 and 100 cm depth), considering a volume of 20% of carbonate accumulations. However, the main implications of carbonate accumulations on vineyard management are related to rootstock selection and ploughing, which should not be too deep to prevent mixing of calcic horizons with surface horizons.

Soil forming processes in Conca de Barberà

The selected Conca de Barberà soils are developed on deposits of gravels coming from the massif of 'Serra de Prades', mainly Carboniferous slates and sandstones, with granodiorite intrusions. During the Quaternary, these deposits covered the Ebro basin margin in the form of alluvial fans, which left two types of gravel deposits. There are ancient deposits, hanged at a considerable height over the current river bed, and other modern deposits, at a little height about the current river bed and connected with the fluvial terraces.

The modern deposits correspond to extensive, flattened alluvial cones, merged with each other, which are formed by Paleozoic materials (mainly slates) and with little matrix. In soils developed from these deposits, a process of clay accumulation is identified, in the form of coatings (<0.05 mm) and infillings (<0.25 mm) of clay, covering the pores and sides of coarse components (Fig. 8). These coatings are quite impure, showing silt and clay embedded. The clay origin is probably the neoformation from mica alteration, since many coatings with embedded altered mica crystals could be observed. Many of these coatings are fragmented and incorporated into the micromass. Other authors found that in these conditions the clay origin is probably clay neoformation from mica (Mermut and Jongerius, 1980; McKeague, 1983).

The old deposits were much more extensive before, so that now some vestiges are only preserved. These deposits have a thickness of 3-4 m and are formed by very weathered polygenic gravels (granodiorites, sandstones and slates) and reddish cement composed of clay and sand. In these soils, processes of clay and carbonate illuviation are identified. The textural features are coatings and infillings of microlaminated pure clay, up to 0.8 mm width, covering the cracks and sides of coarse components and pores (Fig. 9). Many of these coatings are fragmented and incorporated to micromass, so few of them are related to present pores. The carbonate-related features described in the field are carbonate pendants (up to 15 mm width), and microscopically the described features are microsparite coatings and infillings in pores, and sometimes on clay coatings, sparite pendants, micritic nodules and fragments of laminar petrocalcic horizons.

Both soils presented redoximorphic features, in the form of suborthic manganese nodules, between 0.1 and 1 mm of diameter, with rounded shapes and clear limits (not impregnative). The nodules in old deposits are more frequent and more altered than nodules in modern deposits. In general, the presence of these nodules indicates an incipient hydromorphy. However, in old deposits a paleohidromorphy seems more probable.

The soils of modern deposits are classified as Inceptisols, since the

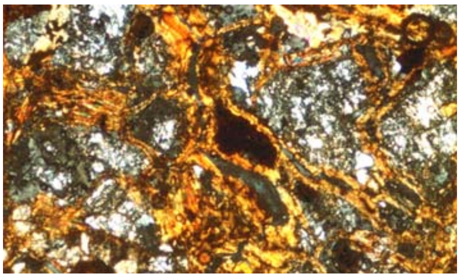

Figure 8. Clay neoformation from mica alteration in Fluventic Haploxerepts: clay coatings on pores and infillings (3.36 mm width, XPL).

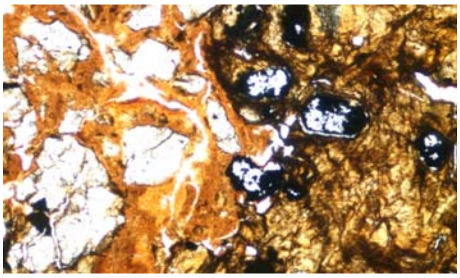

Figure 9. Clay illuviation in Calcic Palexeralfs: rubefacted clay coatings on pores (3.36 mm width, XPL).

rubefaction process associated with the clay accumulation is enough developed to identify a cambic horizon. The soils of old deposits are classified as Alfisols, which are characterized by illuvial clay accumulation. The classification at subgroup level is Calcic Palexeralfs, since carbonate accumulations are enough developed to define a calcic horizon. Thus, it is evident how a longer time of soil formation allows in these deposits a higher number of soil forming processes. Comparing both soils, the soils of old deposits are redder, with significant higher content of clay, available water capacity (in deep horizons) and cation exchange capacity (Table 4). However, their deep horizons are significantly more compacted, which meant a major limitation to root development.

The soil forming processes of these soils have a direct influence on their physical properties. In the modern gravel deposits, which a priori could have very quick drainage because of gravels, the clay neoformation makes possible the existence of more balanced textures, allowing a moderate to high available water capacity (AWC). These soils have very favourable properties for grapevine cultivation, as the balanced textures assure minimal water retention and the gravels facilitate the drainage of water surplus. In addition, these soils favour the development of a deep root system, so that in years of drought the roots could take water from deep water tables. In the old gravel deposits, the properties are more unfavourable than other soils, because the roots have more difficulties to explore deep horizons. This is due to a greater compactness, related to higher clay content. Moreover, the presence of fragments of laminar petrocalcic and other forms of accumulations, which are representative of a long genetic process, are indicative of possible problems related to micromass cementation. However, these soils have a moderate to high AWC, inferred by the clayey matrix and the relatively porous rock fragments, which are capable to retain water.

Soils affected by human activities

In the study area, some soils where human activity caused major changes in soil composition are found. The main changes are related to topography and horizon arrangement. The main effects described as a result of these changes are the buried of fertile surface horizons, and horizons not arranged in any discernible order. One of the features used to determine human activity is the presence of very abrupt limits between horizons.

Table 4. Analytical properties of representative vineyard soils in Conca de Barberà region [c].

Properties	Horizon	Fine loamy, mixed, active, mesic, Fluventic Haploxerepts	Loamy-skeletal, mixed, active, mesic, Calcic Palexeralfs
Soil Forming Processes		Clay neoformation from mica weathering, clay coatings on pores. Incipient hydromorphy.	Clay illuviation and recarbonation, clay coatings and sparite pendants on coarse components. Palaeohydromorphy.
Genetic horizon (SSS, 2006)	**1**	Ap_1	Ap_1
	2	Ap_2	Ap_2
	3	Bw	Btk
Lower depth (cm)	**1**	20.5 (0.96) a	13.4 (0.99) b
	2	45.8 (1.54) a	40.8 (0.93) b
	3	107.1 (2.23) ns	92.8 (7.94) ns
Munsell Colour	**1**	7.5YR3/3	5YR4/6
	2	7.5YR3/4	5YR4/7
	3	5YR4/6	5YR4/8
pH (H_2O 1:2.5)	**1**	8.4 (0.05) ns	8.5 (0.04) ns
	2	8.4 (0.08) ns	8.5 (0.04) ns
	3	8.4 (0.03) ns	8.5 (0.07) ns
Electrical Conductivity (dS/m)	**1**	0.17 (0.01) ns	0.18 (0.01) ns
	2	0.18 (0.01) ns	0.19 (0.01) ns
	3	0.19 (0.01) ns	0.19 (0.01) ns

[c] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

Continued…..

Properties	Horizon	Fine loamy, mixed, active, mesic, Fluventic Haploxerepts	Loamy-skeletal, mixed, active, mesic, Calcic Palexeralfs
Soil Forming Processes		Clay neoformation from mica weathering, clay coatings on pores. Incipient hydromorphy.	Clay illuviation and recarbonation, clay coatings and sparite pendants on coarse components. Palaeohydromorphy.
Organic matter (%)	**1**	2.1 (0.55) a	1.1 (0.10) b
	2	1.8 (0.44) a	0.7 (0.14) b
	3	1.4 (0.45) ns	0.6 (0.11) ns
$CaCO_3$ (%)	**1**	10.2 (2.15) ns	13.7 (4.24) ns
	2	9.2 (1.49) ns	11.8 (3.13) ns
	3	7.4 (2.20) b	17.6 (3.39) a
Cation Exchange Capacity ($cmol_c/kg$)	**1**	11.1 (0.55) b	13.8 (0.23) a
	2	12.2 (0.65) ns	14.2 (0.35) ns
	3	10.5 (1.08) b	13.3 (0.26) a
Sand (%)	**1**	50.4 (2.12) ns	49.8 (1.89) ns
	2	46.9 (0.84) ns	51.1 (2.19) ns
	3	46.5 (2.20) b	52.6 (0.38) a
Silt (%)	**1**	31.8 (1.70) a	23.9 (0.31) b
	2	33.7 (0.64) a	21.2 (0.95) b
	3	35.1 (1.00) a	17.8 (1.09) b
Clay (%)	**1**	17.7 (0.83) b	26.3 (1.60) a
	2	19.4 (0.23) b	27.7 (1.40) a
	3	18.4 (1.20) b	29.6 (0.99) a

[c] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

Continued……

Properties	Horizon	Fine loamy, mixed, active, mesic, Fluventic Haploxerepts	Loamy-skeletal, mixed, active, mesic, Calcic Palexeralfs
Soil Forming Processes		Clay neoformation from mica weathering, clay coatings on pores. Incipient hydromorphy.	Clay illuviation and recarbonation, clay coatings and sparite pendants on coarse components. Palaeohydromorphy.
Textural class (SSS, 2006)	**1**	Loam	Sandy clay loam
	2	Loam	Sandy clay loam
	3	Loam	Sandy clay loam
Bulk density (kg/m^3)	**1**	1299.6 (44.59) ns	1312.0 (18.15) ns
	2	1514.3 (33.76) ns	1525.3 (15.17) ns
	3	1453.1 (11.45) b	1787.0 (45.35) a
Coarse fragments (%)	**1**	11.9 (3.51) ns	9.0 (1.73) ns
	2	12.7 (1.48) ns	6.7 (1.76) ns
	3	26.2 (3.58) a	12.4 (0.49) b
Water retention at 1/3-bar (%)	**1**	20.3 (0.33) a	18.0 (0.58) b
	2	21.7 (0.88) ns	20.7 (0.67) ns
	3	20.0 (0.37) ns	20.3 (0.33) ns
Water retention at 15-bar (%)	**1**	8.3 (0.33) ns	7.3 (0.33) ns
	2	9.7 (0.88) ns	9.0 (0.58) ns
	3	9.5 (0.34) b	11.7 (0.33) a
Available Water Capacity (mm/10 cm)	**1**	13.8 (1.01) ns	12.7 (0.78) ns
	2	15.9 (0.55) ns	16.6 (1.82) ns
	3	11.3 (0.64) b	13.5 (0.21) a

[c] Numbers between brackets correspond to standard errors and different letters indicate significant differences ($p < 0.05$) among the same horizons of different soil series, according to Newman-Keuls test (n=3).

Properties of two soils deeply affected by men are shown in Table 5. Both profiles are classified as Entisols. One soil present an argillic horizon inserted among other horizons that have no relation with its formation. This soil is classified into the suborder Arents, because of the presence of fragments of a diagnostic horizon. When this diagnostic horizon is an argillic, in a xeric regime, soils can be classified as Alfic Xerarents. The other profile, which corresponds to a soil with a buried horizon, does not contain any diagnostic horizon. So, this soil cannot be classified as Arents. In this particular case, the soil is classified as Fluvents, since an irregular decrease in content of organic carbon occurs. Thus, despite the drastic change in profile composition, the anthropic soil origin is not reflected in its classification.

The soils formed by land levelling may have serious problems of soil erosion and often produce a negative effect on productivity and vigour of vines, and also on grape quality, especially in white varieties, due to a decrease in acidity and aromatic potential (Bazzofi *et al*., 2009). However, soils deeply affected by men cannot always be considered worse than unaltered soils, because sometimes grape quality is better in less fertile soils, especially in red varieties. Bazzofi *et al.* (2009) found a significant increase in the content of anthocyanins and total polyphenols of grape berries on soils affected by land levelling, improving grape quality for red wines. Moreover, in table grape production areas of Sicily (Italy) strong earthworks are conducted to bury fertile surface horizons with calcareous materials, in order to improve grape quality (Dazzi, 2008).

CONCLUSIONS

In the region of the Catalan Coastal Range (Catalonia, Spain), a high variety of soil forming processes has been identified, in relation to the existing differences in soil forming factors. In this study, we found that the soil forming processes, identified through morphological and micromorphological analyses, have significant effects on soil properties. The different processes of clay accumulation in soils developed from granodiorites in Priorat or gravel deposits in Conca de Barberà, are primarily responsible for significant differences in clay content, available water capacity and cation exchange capacity. Similarly, carbonate accumulation in Penedès soils have significant effects on calcium carbonate content and also on available water capacity. These soil properties, especially those related to soil moisture regime, available water capacity and calcium carbonate content have a direct influence on the type of management and quality of grapevine production according to different authors. Especially important are the effects that have drastic earthworks on profile characteristics. However, soil classification does not always reflect these important pedogenic processes which have remarkable implications on vineyard soil management. For instance, clay accumulations in soils developed from slates in Priorat, incipient carbonate accumulations in Penedès, or drastic changes in the arrangement of horizons, with a decrease in soil fertility, in the case of soils modified by man. The main conclusion of this study is that parent material or climate alone cannot be used in viticultural zoning at very detailed

Table 5. Analytical properties of 2 soil profiles affected by anthropogenic activities [d].

Horizon	Lower depth (cm)	Munsell color (moist)	pH (H_2O 1:2.5)	EC (dS/m)	Organic matter (%)	$CaCO_3$ (%)	CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Textural class (SSS, 2006)	Bulk density (kg/m^3)	Coarse fragment (%)	Water retention 1/3-bar (%)	Water retention 15-bar (%)	AWC (mm)
Fine loamy, mixed, active, mesic, Alfic Xerarents.																
Accumulations (55/60-80 cm depth): Illuvial clay coatings.																
Ap	40/45	7.5YR4/6	8.4	0.16	0.7	12	14.7	45.2	28.4	26.4	L	1228	20	22	11	45
Ab	55/60	7.5YR4/4	8.3	0.23	1.1	6	10.3	57.3	25.9	16.8	SaL	1360	20	18	8	17
2Bt	80	5YR4/4	8.3	0.22	1.3	trace	16.2	39.5	27.7	32.8	CL	1350	20	24	13	25
3Bw	120	7.5YR4/6	8.3	0.23	1.3	15	12.8	47.3	29.8	22.9	L	1319	20	20	10	42
Loamy-skeletal mixed, superactive, mesic, Typic Xerofluvents																
Ap	15	7.5YR4/6	8.1	0.19	0.76	24	9.8	37.6	47.5	14.9	L	1435	5	22	8	29
Bw	60	7.5YR4/6	8.5	0.19	0.29	16	7.7	38.8	48.7	12.5	L	1580	10	14	7	45
2Ab	100	10YR3/2	8.4	0.16	1.81	trace	10.0	56.6	33.1	10.3	SaL	1250	40	17	8	27

[d] EC: electrical conductivity; CEC: cation exchange capacity; Textural classes: SaL: sandy loam, L: loam, CL: clay loam; AWC: available water capacity.

scale, unless soil forming processes are taken into account.

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