GEOLOGICAL INFLUENCES ON TERROIR DEVELOPMENT

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INTRODUCTION

Terroir is concerned with the relationship between the organoleptic characteristics of a wine and its geographic origin, which might influence these characteristics. Terroir is difficult to study on a scientific basis because many factors are involved, including climate, soil, cultivar and human activities, and these factors interact (Van Leeuwen and Seguin 2006). Among them, soils, with their origin and evolution, leave an imprint on the wine organoleptic profile that testify an origin, a place. In this context geology plays a crucial role in wine quality and is deemed to be an important component of terroir (Maltman 2008). Geology includes the geochemistry, petrology and texture of individual strata, surface water and ground water flow rates and chemistry (Haynes 1999).

The nature of rock and its geomorphological history affects soil physical and chemical composition and the shape of the landscape, conferring morphology, typical spaces and articulations that characterize a production district. Geology also influences the morphology of a territory and thus the meso-climate of a vineyard, through the altitude, the aspect of the slope, the exposure, etc.

The nature of rock governs deep drainage, but also the quality of groundwater and irrigation water. A relevant characteristic of rock is the degree of its resistance to root penetration. This property derives from rock type, presence of planes of weakness, their spacing and orientation (Myburgh et al. 1996). The foliation of schist provides surfaces for roots penetration in an otherwise impenetrable material. For instance, the Upper Douro area of Portugal, in which some of the best grapes are produced, is characterized by soils that are exceedingly thin and offer little water storage. The granite bedrock is massive and root penetration is therefore low. In contrast, the foliation (schistosity) intrinsic to schists not only provides weak surfaces but also generally in the Upper Douro it is steeply dipping or vertical, ideally oriented for roots to exploit (Maltman 2008).

The geological and geomorphological history of a territory dynamically interacts with climate, vegetation and other living organisms, as well as with human activities, leading to soil formation. The soil of a vineyard is a complex system coming out from a succession of rhexistasy and biostasy periods (periods of soil formation – pedogenesis), during which rocks and sediments are weathered, transformed and translocated, leached and depleted, eroded and accumulated, mixed with organic particles, and organized in micro, meso, and macrostructures (Erhart 1956). Apart from vineyards sited on alluvial deposits, virtually all vineyard soils are derived from the underlying or immediately upslope bedrock. The nature of this bedrock greatly influences the physical and chemical properties of the soil, such as pH, texture, structure, color and nutrient composition, and consequently the vine-root growth (Morlat and Jacquet 1993).

For instance, soil pH is important for its effect on the availability of several nutrients, micronutrients and extremes in pH inhibit root growth. Values below 5.5 or above 10 are deemed too acidic or too basic to sustain grapevine growth (Neirynck 2009). Soil texture and structure influence the soil's water holding capacity, drainage and the ease of root penetration (White 2009).

White (2009) divided the soil according to their geological characteristics in low and high potential sites for growing vines. Low potential sites have clastic sedimentary or metamorphic rocks with little weatherable mineral remains, and exhibit shallow soils, with little water holding capacity, lower or high pH, little organic matter and low nitrogen content. High potential sites are often igneous rocks, or limestones, plus metamorphic rocks and alluvium from the above rocks. These soil are well drained, deep and rich in organic matter.

However each grape variety expresses its best productive performance in a specific type of soil and this linkage between a particular variety with the geology of a grape-growing area contributes to the terroir of a peculiar region.

The geology of a soil gives different flavors and aromas to wines: calcareous soils produce lemon and citrus flavored wines with a long acid finish. Marl soils and silty calcareous soils tend to generate peppery flavors. Sandstone soils tend to bring a "nervy" character to the wines, the fine-grained clay soils emphasize tannic characteristics and volcanic soils produce full-bodied wine with smoke-based aromas (Burns 2012).

In this report four Italian cases of study will be discussed in which four grape-growing areas are characterized by two different geological soils. For each area of investigation, the influence of geological features of the vineyard on the wine characteristics is assessed in order to highlight the differences between the wines produced from soils with different geological origin. These examples are taken from the zonation studies carried out by CREA-VIT in the last 20 years.

Keywords: terroir, soil, geology, flavor, geographic origin, volcanic soil, calcareous soil.

FIRST CASE OF STUDY: CANNONAU OF JERZU

The Jerzu wine growing area, located in the Province of Nuoro close to the eastern cost of Sardinia, is one of the most prestigious areas where Cannonau DOC of Sardinia wine is produced. The Jerzu area, encompasses approximately 7.000 ha of land, 800 of which are destined to the cultivation of Cannonau grape variety. The geomorphology of this area is the result of different morphogenetic processes that generated two main distinct landscapes: on one side mountains and hills at elevations ranging from 300 to 800 m a.s.l.; on the other side, below 300 m a.s.l., alluvial plans and valleys.

This geomorphologic configuration is the synthesis of a series of events performed over the course of hundreds of millions of years, from the Paleozoic to the present.

The mountains are formed from rocks of the Paleozoic era (age 550-290 million years) both from metamorphic and magmatic origin. The western zone of the area is mainly metamorphic, while the eastern one is mainly granitic.

These two rock formations have a different response to the processes of weathering and erosion because of their different mineralogical composition and different petrographic structure.

The granitic reliefs of Jerzu's area, due to the rugged morphologies and steep slopes, are mostly characterized by rocky outcrops; at the base of the slopes, it develop layers of sandy debris. The granite rocks, in fact, composed of feldspar and quartz in crystalline form, undergo the sandstone formation process that generates sometimes even thick layers of detritus with a high sandy component.

Also the reliefs metamorphic rocks are often bare and rocky, but on the side of fitting with the bottom of the valley, at different levels (e.g. slopes of Sa Canna), there are debris of silty-clay matrix, distributed at the "leopard skin", derived from the disassembly of the metamorphic schistose rocks.

Soils with fair depth and a good degree of fertility have been developed on these deposits, and these areas are characterized by very old vineyards.

The river valleys, that characterized the landscape of the vineyards of Jerzu's Cannonau, have hosted the main rivers since ancient times, and are still engraving by the present the water courses (Rio of Quirra, Fiume Pelau, Rio Pardu, Rio Flumini). The river valleys were affected, since their ancient formation, from the deposition of alluvial sediments in consecutive events, starting from a few thousand years up to our days. The floods have led to the deposition of very coarse material in the past, and thinner sediments such as gravels, sands, silts, and clays, in more recent times (Figure 1).

There is a great variety of rocks and sediments of different ages, which constitute the territory of the Cannonau of Jerzu; their different process of alteration, the exposure to various climatic factors (precipitation, temperature, humidity, presence of groundwater, etc.) and the human activities present ages ago, have produced soils with peculiar chemical, structural and physical characters. All these have an evident impact on the qualitative characteristics of the grapes and the resulting wines.

In areas of the valley floors, as previously mentioned, there are soils generated by both the ancient alluvial deposits and recent ones.

The useful depth for the roots varies from moderate to very high, but the high pebble content limits the amount of water available to the plant, limiting the vigor of the plant and thus favoring an optimal ripening process. In areas of slope, viticulture is concentrated mainly in correspondence of the valleys, where soils are deeper and have a structure and a texture able to effectively support the cultivation of the vine. The surface of these soils is characterized by the contribution of organic matter, and it is porous and easily penetrable by the water. It is supported on ancient soils, reddened, rich in clay and therefore able to preserve longer the water resource. This soil ecosystem is very important for cultivation of vine, as it has been shown from the qualitative responses observed in Cannonau grape during the study of zoning carried out in this area. The soluble solid content is always on average high, which is reflected in good values of acidity, and these data have confirmed the excellent metabolisms of ripeness and the overall freshness of the grapes grown in these soils.

The wines of the valley floors are characterized by a well-defined imprint of richness and maturity. The wine is round and intense, the tannins are little perceived, and surprising to the nose, a fruity fragrance, intense and harmonic. Unlike the valley floor, the wines obtained in the slope zones, show a good structure given by both tannins and freshness. The fruity notes are present but not prevalent, they are surpassed by those of floral and spicy (Figure 2). Also the body is much more important than those of the wines produced on the valley floors and expresses its strength with a remarkable finesse (Tomasi and Gaiotti 2012).

SECOND CASE OF STUDY: THE PROSECCO DOCG AREA

The DOCG Prosecco area displays a great variety of geomorphological environments, in which the various morphogenetic processes have acted, and continue to act, upon differentiated geological substrates.

The variety in this hilly landscape owes its origin primarily to the phenomena of differential erosion, called morphoselection, where the presence of more resistant, more "competent" lithologies, such as for example limestones, as opposed to softer rocks such as marls, creates great contrasts in terms of dips and aggregate slope morphologies.

A further complicating element in the geomorphological evolution of the DOCG Prosecco area is constituted by the environmental changes that followed each other during the Quaternary. These variations were connected to the well-known climatic fluctuations on a global scale that, at their extremes, caused alternating glacial and interglacial cycles. The last glaciation, known traditionally in the Alpine area as the Wurm, reached its apex between around 25,000 and 15,000 years ago. In this period, just as during the previous glaciations, a large part of the Alpine area was covered by glaciers, which descended along the valleys, in thicknesses of hundreds of meters. In the Veneto area, the eastern branch of the Piave glacier, the Lapisino, reached the plains at Vittorio Veneto, building up the homonymous morainic amphitheater.
The complex geomorphologic picture just outlined, explains the number and difference of soils present in this area. Marly and morainic hills will be described, as two representative and very different Glera grape (and its Prosecco wine) production contexts.

Glera grape production in soils over marl
Much of the northern part of the Prosecco DOCG zone is composed of hills rising above a marly substrate formed in the Tertiary period. Morphologically speaking, the area is characterized by gently rolling, regular inclines, alternating with steeper, more rugged slopes, where the vineyards cling to the hillsides.
The soils of this hilly area are above all notable for their great depth and the lack of rock fragments, even in the steepest slopes, where erosive phenomena are effectively checked by grassing. These factors ensure sufficient water reserves for the vine throughout the year, mainly because of the original rocky substrate, but also thanks to optimal exploration of the deeper soil layers by the root system. This keeps the plants vigorous and production yields high, despite the fact that some rainwater is lost as a result of surface runoff. The wines are notable for their elegance, lightness, and excellent drinkability. The aromatic components, rich in monoterpenes and secondary norisoprenoids, abound in floral aromas of spring flowers, and fruit aromas of peach, apricot, pear, citrus fruit and apple, endowing the wines with great complexity and aromatic intensity (Figure 3). Good levels of acidity provide freshness, and on the palate the wines are velvety, with delicate, lean body and well-orchestrated acidity, finishing with a dry aftertaste.

Glera grape production in morainic soils
Glaciations have contributed over the millennia to forming the soils we now find in the morainic hills of the Prosecco DOCG. With the retreating of the southern branch of the Piave glacier, the ice melted and carried the eroded materials downhill, forming an extensive morainic area with soils rich in fragmentary material. While displaying the same soft, undulating hills typical of Miocene clay landscapes, the morainic areas of the Prosecco DOCG zone thus differ from the former in terms of their entirely different substrate. The sandyclayey soil is extremely rich in rock fragments and has low effective soil depth. The water reserves are thus very low and at times insufficient, making irrigation necessary even in not particularly dry years. Vine vigor is consequently reduced, and clusters are smaller with more shot berries (Table 1). The wines from these hills are characterized by tropical, floral, citrus, and ripe fruit aromas (figure 3). In dry seasons this wines can suffer from the low acid content of the grapes, which might compromises the achievement of their aromatic potential (Tomasi et al. 2013).

THIRD CASE OF STUDY: THE SOAVE DOC AREA

The Soave DOC District is located in north-eastern Italy and it is an hill area near Verona. The most widespread variety is Garganega, leaving less than 5% to other white grape varieties such as Chardonnay and Trebbiano di Soave. The traditional training method is “pergola veronese”, with a planting density of 2,500 to 3,000 vines per hectare.
The Soave DOC area is characterized by two different types of soils: volcanic and calcarenite soils.
Regarding to the volcanic soil, it is originated from the intense volcanic activity since Tertiary period. This activity continued throughout the geological cycles, all in an underwater environment, which created volcanoclastic products with various colorations, depending on the environment of formation and the level of oxidation. This soil shows a clay texture with a small amount of gravel, it has good permeability and high water-holding capacity. Basaltic soils are mainly present in the eastern part of the DOC area. Wines produced in this soils have good palate and nose intensity, as well as a finesse and balance of flavor (Figure 4). The sensory descriptors more evident are spicy, cinnamon, due to the high benzenoid content, and cherry and wild berries.
The calcarenite soils are present in western part of Soave DOC District and they are characterized by limited depth, low water holding capacity and abundance of pebbles. Lime content is frequently high, rising above levels of 12% of active lime. These soil characteristics restrain the natural vigor of the Garganega variety, containing yields in respect to other zones of the DOC area. Comparing to the wines from volcanic soil, those produced in these limestone soils are characterized by tropical and ripe fruit nuance, due to the high content of norisoprenoids. Floral and citrus touches are also clear, attributable to the good content of terpenes in the grapes (Figure 4). A distinctive mineral tang in the flavor is perceived and is typical of this calcarenite soils (Tomasi and Gaiotti 2010).

FOURTH CASE OF STUDY: THE VALPANTENA AREA

The Valpantena is an important wine area placed in the North-East part of Italy, in the Veneto Region, near the city of Verona. The Valpantena has a North-South orientation and is bordered on the north by the Lessini mountains, on the east and west respectively by the Val di Squaranto and by the Valpolicella, which both share a similar geological origin with the Valpantena, and on the south by the city of Verona and the Adige river.

The rock formations that make up the stratigraphic series of the Valpantena include ancient and deep marine deposits (250-200 Mya), composed of gray limestone, then formations from the Cretaceous age (145-58 Mya) that include different limestone types (eg the 'Rosso ammonitico', the 'Biancone', and the 'Scaglia rossa'). Finally, in the most superficial and recent layer (Eocene-Miocene, 58-5 Mya) there are calcarenites (sandstones), nummulite limestones, and scattered basaltic intrusions of volcanic origin (Figure 5).

The erosive process conducted by Prealpine streams has given rise to the valley floor portion of the Valpantena, distinguished by different particle size as a function of solid transport capacity of water courses, and generally characterized by a carbonatic lithology. In the upstream areas, in the presence of steeper slopes, the deposits are rough with unaltered gravel since the surface; conversely, in the flat areas the deposits are mostly sandy-loam or loam, and with little gravel content.

The hills close to the Valpantena floodplain are almost exclusively made of limestone and reach 600 meters in height. The paleo-landslide and erosive events, caused by rain water flows along the slopes, have resulted in the formation of homogeneous deposits of clay and silty material, mixed with gravel, along the foot of the hills. These sub-flat areas, characterized by well-differentiated and deep soil, have a relatively modest carbonates content, and are the most intensively cultivated for wine grapes production. On the contrary, the higher hillsides that were interested from erosion have shallow and poorly developed soils that make the viticulture more difficult.

The winemaking tradition in the area of the Valpantena has very ancient origins, likely present already in the Roman times, and is currently addressed to the production of high quality wines such as the 'Amarone della Valpolicella', the 'Valpolicella Superiore' and the 'Recioto della Valpolicella'. In this territory, the local varieties 'Corvina', 'Rondinella' and 'Corvinone' are principally spread.

Data obtained from a zoning project of the Valpantena showed the effect of geological factors in respect to the grape and wine quality aspects. In particular, plant responses to different local rocks formations, such as the 'Biancone' and the 'Scaglia Rossa' were observed. The Valpantena's rock formations all share a common calcareous composition: the 'Biancone' consists of marly limestone, thickly layered, and easily erodible (K factor> 0.25). The 'Scaglia Rossa' type is made up of white-pink limestone, densely layered, rich in planktonic fossils, moderately erodible (K factor <0.15).

In grapes of 'Corvina' harvested in medium-hill areas with 'Scaglia Rossa', the content of malic acid was on average lower than in grapes produced in areas with the 'Biancone' type formation, while an opposite situation was observed for tartaric acid. Even the accumulation of pigments differed in the grapes coming from the two formations: the grapes from the 'Scaglia Rossa' showed a slight increase in the total anthocyanin content.

More generally, the wines made from grapes harvested in the hilly areas of Valpantena are characterized by a good supply in color, strong aromatic notes of red fruits (cherry, blackberry – Figure 6), which intensifies further through the post-harvest withering (Battista and Tomasi 2014).

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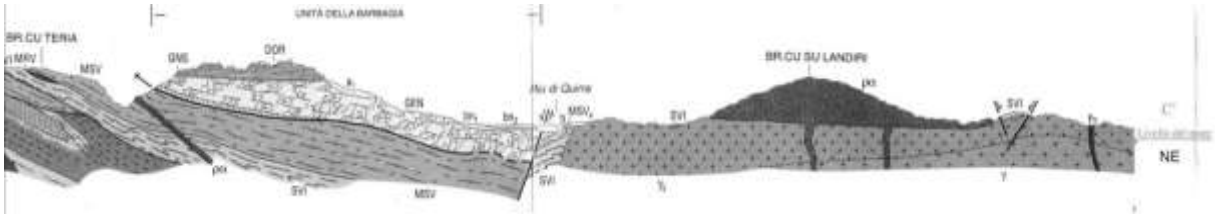

Figure 1: Schematic section of the geological structure of the territory of Jerzu. Extracted from: the Geological map of the Autonomous Region of Sardinia.

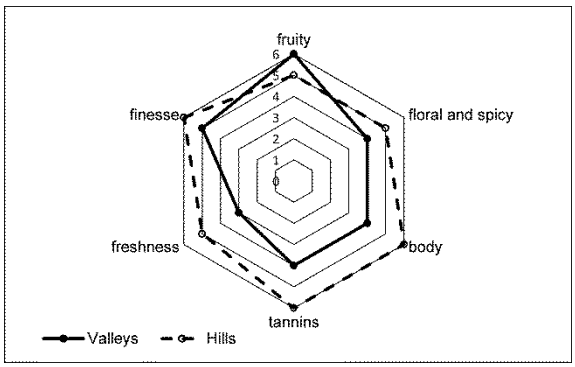

Figure 2: Sensory profile of Cannonau wines from hilly and valley areas of Jerzu Region.

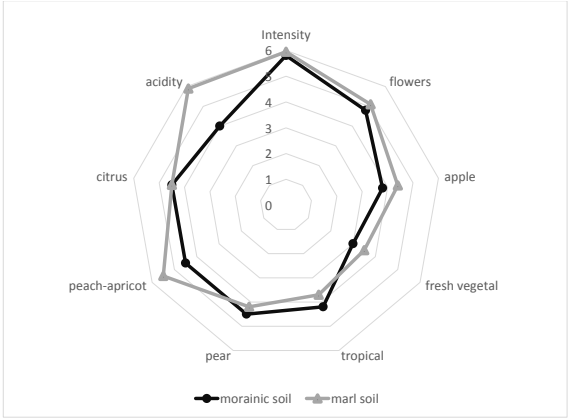

Figure 3: Sensory profile of Prosecco wines produced on marl and morainic soils.

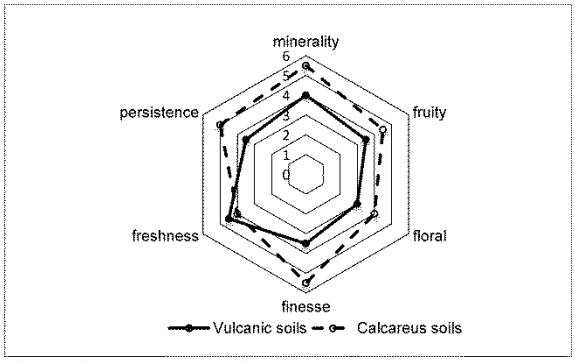

Figure 4: Sensory profile of Soave wines from volcanic soils compared to calcareous soils.

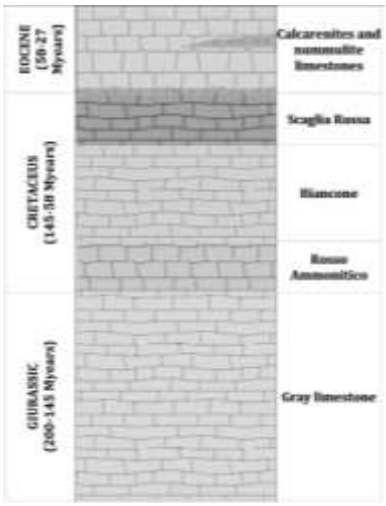

Figure 5: Simplified stratigraphic section in the Valpantena area.

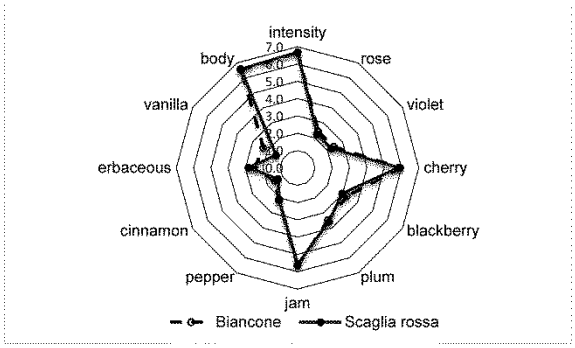

Figure 6: Sensory profile of dried Corvina wines from the Valpantena hilly areas. Wines from Biancone type formations are compared to those from Scaglia Rossa.

Table 1: Characteristics of Glera grape production and quality on marl and morainic soils in the DOCG Prosecco area.

Parameter	Marl soil	Morainic soil
Sugars (g/L)	160	158
Titratable acidity (g/L)	8.0	6.3
Bunch weight (g)	270	245
Berry weight (g)	1.5	1.2