

Great Burgundy Wines

A Principal Components Analysis of "La Côte" vineyards

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Résumé

Cet article examine les conditions physiques des terroirs viticoles de Bourgogne dénommés “Côte de Nuits” et “Côte de Beaune”.

La méthodologie utilisée est celle de l’analyse en composantes principales. Elle est appliquée à 14 variables décrivant les sols et 4 variables décrivant les paysages.

L’analyse permet de structurer la population des 2816 vignobles examinés selon 3 variables principales, d’une part, en ce qui concerne les sols, soit présence de colluvions, soit présence de calcaire compact (avec des variantes de calcaires biodétritiques, fossilifères ou grenus), et, d’autre part, en ce qui concerne le paysage, la pente (en corrélation avec l’altitude). La combinaison de ces variables conduit à une répartition des vignobles en deux groupes principaux, auxquels il faut ajouter un troisième groupe, moins important, coïncidant avec la présence d’alluvions sur des sols à des altitudes plutôt basses, peu pentus, et en exposition sud.

L’analyse met en outre en évidence une certaine variabilité dans les caractéristiques physiques des sols des vignobles, quand bien même seuls ceux portant des Grands Crus seraient pris en compte. Ceci montre l’importance du facteur humain dans le processus complet de production des grands vins.

Abstract

This paper examines the physical conditions of the Burgundy Côte de Nuits and Côte de Beaune wine terroirs.

Principal components analysis has been used as a methodology, applied to 14 soil and 4 landscape description variables.

The analysis shows three major variables structuring the entire map of the 2816 examined vineyards: i) on the side of soils, either colluvium, or, dominantly compact limestone (with alternatives of

biodetritic, porous or granular limestone), ii) on the side of landscape, slope (together with altitude). The combination of these variables dispatches the entire population of vineyards into two major groups. An additional smaller group appears along with the presence of alluvial grounds on south facing lower and weak slopes grounds.

There is nevertheless a margin of variability in the physical characterisation of the vineyards, even when only the *Grands Crus* are taken into account. This demonstrates the relevance of the human factor in the entire process of great wines production.

Keywords

Burgundy, Chardonnay, climat, colluvium, côte, cru, geology, landscape, limestone, multivariate, Pinot Noir, raciness, soil, terroir, vineyards, wine

Overview

An examination of physical conditions...

This paper examines vineyards located in the areas denominated *Côte de Nuits* and *Côte de Beaune* in Burgundy, together with sets of variables characterising their *terroirs*.

Geologic and climatic data are used. The data base consists of 2816 vineyard sites, exclusively within the *Côte de Nuits* and *Côte de Beaune*, *Communale*, *Premiers Crus* and *Grands Crus* AOC (*Appellation d'Origine Contrôlée*). The Regional AOCs are not in the study. Besides its AOC classification (Y variables), each vineyard is described with 23 variables (X variables) on basis of which principal components analysis can be applied.

The X variables are intended to describe the soil and its structure (geology and pedology), watering and drainage, climatology, etc. In this paper only 18 of these X variables are presented. They are classified into two groups: *landscape variables*, characterising the *outside* – visible – environment of the vineyard site, and *soil variables*, characterising the *inside* – invisible – environment of the vineyard site.

The principal components methodology applied in this paper con-

sists into identifying the relevant combination of these characteristics and map them, together with the vineyards and the reference scheme used in Burgundy for their labelling and classification, based on the concept of “*climat*”. This concept is very similar to that of *terroir*, as defined, for example, by the American geologist James E. Wilson (1998), after he learned of that word during geological journeys in Burgundy “*it includes physical elements of the vineyard habitat – the vine, subsoil, sitting, drainage, and microclimate. Beyond the measurable ecosystem, there is an additional dimension – the spiritual aspect that recognises the joys, the heartbreaks, the pride, the sweat, and the frustrations of its history.*”

Vineyards geographic positions are identified by the coordinates of their centroids. Corresponding landscape and soil data are attached to these centroids. Each vineyard has a *climat* designation, to which the Burgundy AOC classification is referring. The study confronts both sets and, within the classification set, puts special emphasis on the “*Grands Crus*” category.

The findings of the analysis lead to distinguish between 3 categories of conditions favourable to the cultivation of the vine for the production of vintage wines in Burgundy.

Soil is either made of colluvium retained in the curbs of slopes, or of more compact limestone. Both are excellent in maintaining appropriate hydric conditions for vine roots throughout the year, albeit the physical process by which this is achieved is rather different between both. Besides compact limestone, other calcareous soils, granular, biodetritic, or porous also play a positive role.

Concerning landscape influences, the slope and the altitude of the vineyard site play a positive role. The east orientation is an additional positive factor.

The study shows that there is some contradiction between landscape and soil influences, as far as colluvium is concerned. This, from a principal components analysis view point, leads to a clear *no compromise* differentiation of the colluvium category. Evidently, colluvium can neither reside on the top of reliefs, nor on steep slopes, which are more likely to be seen on the east facing side of the Burgundy *Côte*, and would frequently coincide with rather compact limestone grounds when vineyards appropriate for vintage wines are cultivated.

This is an important finding of the study, because it contradicts somewhat a widely spread opinion that *Grands Crus* vineyards dominantly reside at mid slope, and *Premier Crus* further down. This opinion mostly derives from an extrapolation based on studies of the Hill of Corton vineyards, where, besides calcareous soils, colluvium plays also a role.

The principal components analysis shows that both the above- and under- the ground conditions matter. It gives however precedence to the underground, to the extent that a good situation in the landscape would not compensate for unfavourable soils. There are no *Grands Crus* on sandy marls or clayey limestone. In contrast, when the soil provides for excellent hydric conditions you may obtain high class wines such as the *Grands Crus* of the *Montagne de Corton* (the Corton Mountain, in actual facts, the Corton Hill), even if all of the *climats* composing these AOCs are not with an optimum situation in the landscape.

... also showing that the Human factor is key

In the entire process of vine growing and wine making, the human factor is key. There is a need to recognise this dimension: “the spiritual aspect that recognises the joys, the heartbrakes, the pride, the sweat, and the frustrations of its history”, as stated in Wilson’s definition of terroir.

Indeed, a good *terroir* in physical terms would not be conducting to a good wine without the intervention of a good *vigneron*. There is no proper translation for *vigneron* into English. The *vigneron* is a person who is acting on both sides in the entire process of wine making: the agriculture side of the vine cultivation, treatment, pruning (anyone who has not spent some time observing a *vigneron* pruning his vine can understand only little about the art of wine making) and grape collecting, and the in house side of pressing the grape, elaborating the wine in barrels and, furthermore, over watching the complex processes of *esterification* that occurs in the bottles and may after several years lead to some superb wines. Whatever the physical qualities of the terroir, the *vigneron* is key in taking advantage of it, exactly in the same way that a musician is key in playing the music, as no violin would play by itself, even a Stradivarius.

This study – only of the physical conditions in the environment of vine development – shows that, in the background, the human factor is crucial. The *terroir* of Clos-de-Vougeot can be clearly characterised by two sets of soil parameters (colluvium and porous limestone) favouring an excellent *hydrification* (water diffusion) of vine roots. But the *terroirs* of the *Grands Crus* in the area of Vosne-Romanée are more heterogeneous. Richebourg and La Tâche are on colluvium, Romanée-Saint Vivant is on porous limestone and Romanée-Conti is on biodetritic limestone. There is however a common parameter between these *climats* and those of Clos-de-Vougeot. They all used to belong for centuries to the vineyards of the Citeaux Abbey, and were cultivated by the Cistercian monks who developed an entire art in wine making, transmitted in any kind of way to their successors. This is something not easy to identify with a quantitative statistical analysis, but that can perhaps be understood by way of simple contact with some of the people who are today working in these vineyards.

Also, because the concept of *terroir* is today, too frequently, used in some way as equivalent to a concept of *brand* (such as that of a famous drink invented by an Atlanta pharmacist), it is been useful to examine it, independently from the people whose day after day work has built its reputation, and see its strengths and weaknesses for the purpose of marketing, if not to contribute to the advancement of the economic science.

Further developments

This paper, prepared for a 15 minutes conference, does not present all the findings of the analysis. The entire study provides for a more detailed analysis including further geo-climatic variables: sunpower, curvature, rainfall and vineyard surface.

Burgundy, May 10th 2004

Vineyards, data base and methodology

To conduct the study, a data base been constructed. It covers 2816 vineyards in two of the three Burgundy areas where *Grande Crush* AOC have been delivered: *Côte de Nuits* and *Côte de Beaune* (the third area for *Grande Crush* is Chablis). Taken together, *Côte de Nuits* and *Côte de Beaune* form a NNE-SSW direction strip of about 50 km in length, from Marsenay (south of Dijon) to Santenay (near Chagny). This entire area is called “*La Côte*”.

The structure and morphology of “*La Côte*” differs from that of the other vineyards areas forming the entire Burgundy AOC region, which is composed of *Chablisien*, at the northern extremity (cities of Auxerre, Chablis, Tonnerre), the *Chalonnais-Maconnais* (cities of Chalon sur Saône and Macon) in the southern part, and the *Côte* (cities of Dijon, Nuits-Saint-Georges, Beaune and Chagny). Chablisien stands quite a part in the overall picture of Burgundy, because it is separated from the east and south vineyards areas by the old hercynian Morvan massif. Notwithstanding, Chablisien is bearing some of the oldest vineyards of France, such as the famous *Chablis* (white wine) and less known but excellent *Irancy* (red), such vineyards from where the old kings of France used to select their wines.

In contrast, there is some apparent continuity between Chalonnais-Maconnais, and *La Côte* area, as you see almost no interruption in the vineyards sites along the national road linking Dijon to Macon. However there are important differences. Charles Pomerol in “Wine and Vineland of France” (BRGM 1996) describes as follows the specifics of *La Côte* when compared to southern part of Burgundy, Mâconnais and Châlonnais.

- *The Jurassic layers which are monoclinal up to there, become horizontal*
- *The boundary of these Jurassic layers with the Tertiary formations of the Bresse is still a fault contact, with a large throw (600 to 1100 m). The monoclinal structures which plunged regularly under the older alluvials, are replaced by steps with subverticals fault planes. The Côte, with its step fault slopes, consistently dominates the Bresse plain from 150 to 200 m.*

This morphology will determine where the vineyards are sited, i.e. confined to the slopes and piedmont of the Côte, especially those facing east, south-east and south, at altitudes between 225 and 300 m, whilst the vineyards of the Mâconnais and Chalonnais are more dispersed, sometimes facing south-west and west, and are often discontinuous.”

To built the data base, any of the 2816 vineyards identified in the *La Côte* area has been defined in terms of the *Lambert* x,y

coordinates of its *centroid* (i.e the point corresponding more or less to the gravity centre of the area covered by the vineyard). This is an approximate, as there is some variation within a vineyard site, in slope, altitude, and even soil, etc. This is however not of large inconvenience, as in this area the vineyards are rather small in surface. Also, information has been collected on vineyards surfaces, and this can help in appreciating the accuracy of the centroid approximation.

(X) Variables: above and under the ground

A set of 24 variables has been collected to describe each vineyard site, as shown in table 1. Whenever possible, the ordinary measurement system has been used, e.g. altitude in meters, and slope in degree.

Concerning orientation, to avoid issues linked to circular variables in measuring orientation vis-à-vis the North, it has been broken down into two orthogonal variables: east and south Orientation – notice that this is different from the way orientation is measured in

Table 1 – (X) variables in the data base

The 9 landscape and climatic description variables	The 14 soil description variables
Altitude	Alluvial deposits
Slope	Clay with silicate sand
Orientation East	Compact limestone
Orientation South	Clayey Limestone (80%<C03<90%)
* Sunpower March	Biotrititic Limestone
* Sunpower June	Fossil/Porous Limestone
* Annual Average Rainfall	Granular limestone
* Curvature	Marly limestone
* Surface of site	Oolitic limestone
	Colluvium
	Scrap from extracting industries
	Marl (33%<C03<66%)
	Sandy marl
	Ferruginous oolite

* = Variables not presented in this paper

the paper of Orley Ashenfelter and Karl Stochmann, on Mosel valley wines. A measurement of curvature (i.e. convexity/concavity) of each site is also in the data base, it measures changes in slope over the 8 neighbouring 50 meters meshes of the site centroid, from 1 (maximum convexity) to -1 (maximum concavity).

In actual facts, as the principal components analysis is being done on basis of standardised variables (by subtracting their means and dividing by their standard deviation), the initial scales of measurement are not reflected in the results of the computation.

Soil description has been established according to geologic standards and wordings, using the “official” simplified classification scheme. In the data base, the presence of an item of this geologic classification is signalled with 1 and its absence with zero.

The principal components analysis presented in this paper is based on all of the 14 soil description variables, but only on 4 out of the 9 landscape/climatic description variables (with all the vineyards).

Only for the convenience of the exposé, variables are classified into two groups: *landscape variables*, characterising the *outside* – visible – environment of the vineyard site, and *soil variables*, characterising the *inside* – invisible – environment of the vineyard site. But the principal components analysis here presented is *ex ante* taking all of them together. Of course, a structured analysis, based on the partial least squares methodology authorises the construction of a more sophisticated hierarchical model.

In this “open-to-the-public” paper, all variables are number coded, on the charts and tables with a preceding letter: L for *landscape* and S for *soil*. Written comments provide information on the significance of relevant variables.

It also matters to explain that within the set of AOCs studied (see next), there are two vine types permitted in Burgundy: Pinot Noir (and its varieties of Pinot *Gris* or *Beurot* and Pinot *Liébault*) and Chardonnay. There are only one or two exceptions to this rule with the Aligoté being used instead of Chardonnay, and Pinot Gris being combined with Chardonnay (white premier cru of Clos blanc Monopole cultivated on the commune of Vougeot).

(Y) variables: the Burgundy referential

In the data base, the Y variables set is simply formed of the *Côte de Nuits* and *Côte de Beaune* AOC labelling attached to the vine-

yards under scrutiny. These AOCs are delivered according to the Burgundy rules for this classification. It has to be understood that in contrast to the well known lunacy of French regulators to favour “*centralisme*” (everything decided in Paris), the Burgundy AOC rules have been set up locally, and are even different from one place to another. They all suppose the existing of a sort of unit for the cultivation of vine and production of wine. This unit is called *climat* in Burgundy.

A climat doesn't necessarily coincide with a unique piece of land, even not necessarily with adjacent sites. It is however in any case composed of vineyards that can be geographically identified. For example the Clos-de-Vougeot is composed of several vineyards, that are all near each other and form a continuous territorial unity. Within Clos-de-Vougeot, there are some 16 territorial entities (and about 70 owners) for a total surface of only 50 ha. Because all of these parcels are classified *Grand Cru* there is no reference to *climat* in the labelling. It is simply called “*Clos-de-Vougeot*”. Only the connoisseurs would argue and discuss about whether the best situation in Clos-de-Vougeot is in the north-west boundary, a place called *Musigné*, or more in the south of the site, a place named “*Le Rognon*”, and that was in the old time called “*Le Grand Maupertuis*”.

In contrast, looking at the Vosne-Romanée area, you will find 8 *Grande Crus* (La Romanée, Romanée-Conti, Romanée Saint-Vivant, la Tâche, La Grande Rue, Echézeaux, Grande Echézeaux) all together referring to some 20 *climats*. But within this set, some *Grande Crus* refer to only one *climat*, e.g. La Romanée, which covers only 0.8552 ha, some others cover several *climats* (e.g. Les Grands Echézeaux). But even in the second situation, only the name of the *Grand Cru* is on the label of the bottle, not that of the *climat*.

Now, you move to the Corton *Mountain* and you find some 24 *climats* that can bear the *Grand Cru* “Corton” labelling. Concerning red wines, the labelling “Corton” may be supplemented with an indication of the *climat* (such as “Les Renardes”, les Maréchaudes”, etc.), but this is not possible if it is produced in the Corton-Charlemagne area. Concerning white wines, the production can be from any place in the defined area, but the labelling cannot bear the name of the *climat*, with the exception of the Corton-Vergennes *cuvée* for the Hospices-de-Beaune. In addition, some *climats* in Aloxe and Ladoix can produce both Corton (red and white) and Corton-Charlemagne.

Some would consider this as complex. But indeed, it reflects the local habits in identifying the wines. And in the background, as this study shows, it corresponds to the underlying arrangements of the variables. The Corton *Mountain* has a unity as a hill, and this is the driving force behind the AOC system. There is however a differentiation in the area, linked to the situation on the hill, and this will generate some differences in wine taste; for example, the altitude of *Grands Crus* vary between 246 and 355 m. But such variables are less relevant when we are in the more flat land of Clos-de-Vougeot with altitudes ranging from 247 to 262 m.

One of the preliminary ideas I had in assembling the (Y) variables was to also refer to wine guides. However, in carefully looking into the numerous books rating wines, we indeed find only poor information concerning wines. The wine tasting-notation methodology of most of these guides is not very far away from merely collecting the opinion of the man on the street (or, even worst, the educated journalist whose taste has been spoiled by the abundant time of his youth he spent taking chemical drinks in college cafeterias). The value of his answer would be about the same as if you had asked him to rate a Picasso painting against that of a primary school pupil. And, indeed, in the end, the good books, always refer to the taste of the *vignerons* themselves to frame their recommendations. Of course, for the one who wants to compare a South African wine with another from Burgundy, this might not be enough, as most Burgundy *vignerons* would not care much about South African vines, and conversely.

Another issue turns around the eternal conflict between uniformity and diversity, conformity and deviancy. The market economy has been a big promoter of mass production. To make a long story short, it has transformed the old Ricardian conflict between rent and profit into a new one, between royalties gained out of monopolistic brands, inculcated in the consumer's head by mass advertising, and the pleasure resulting from real individualistic hedonistic sensations, *à la Bentham*. Today, we hear, also in this country, France, that when you order a glass of Chardonnay in any place of the world, it would be better if it tasted the same *Chardonnay way*; otherwise, the *consumer* might be disappointed; in the same way as you had in an American TV ad, a construction worker sitting on the roof of a skyscraper and complaining to his workmate “*they have changed my coke*”. Who can tell me what is the real taste of a Chardonnay? Of course, one day or another, there will be a clear definition of the taste of Chardonnay, and it is like-

ly that this definition will correspond to some sort of white Chardonnay wine from an Australian producer who has the most important world market share.

This is not what we are looking for, when we are analysing the causes and sources of diversity, of uniqueness. Burgundy is one of the remaining regions in this world where some people continue to care about such things as the difference between a Pinot Noir in a Volnay wine and a Pinot Noir in a Pommard wine, despite the fact that both vineyards they come from are not more than 3 km distant from each other.

But indeed, the polarity rent-profit has reversed today. Burgundy *vignerons* were clearly in a rent situation in the old times when two thirds of France's land were in the hands of the Church, and the clergy folks, who had eternity on their side, were producing most of the great wines of *La Côte*. Today, that everyone wants to make money with world-wide brands, and have the wine drunk as soon as possible after it has been bottled, the Burgundy *vigneron* is under the threat of seeing the name of his land disappear behind the holographic picture of a grape from a genetically modified vine, named according to the easiness of being spelled out by chinese people.

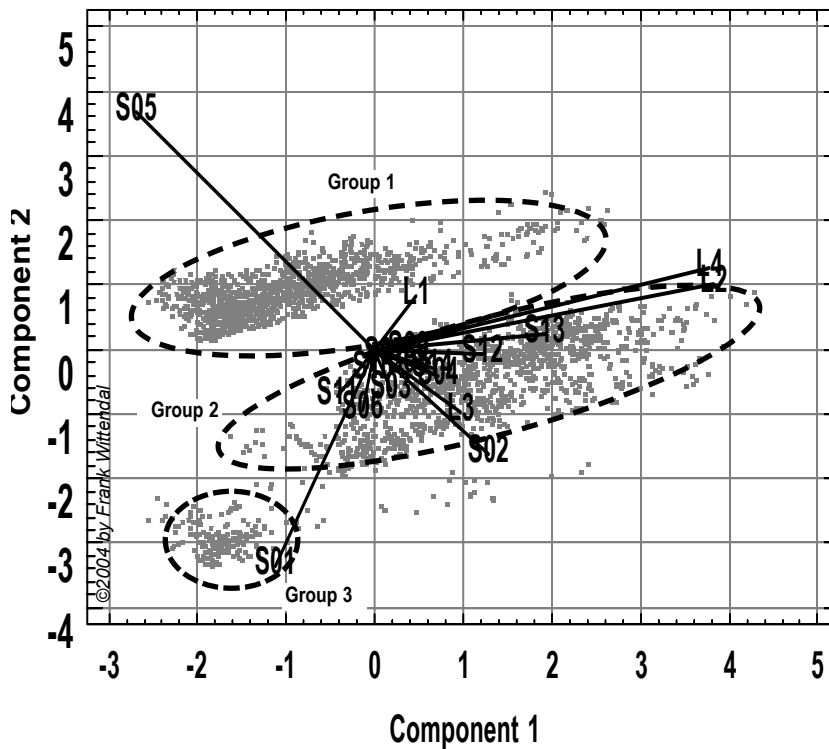
For all the above mentioned reasons, in the end, the set of Y variables chosen in the study is straightforwardly composed of the classification established by the Burgundy *vignerons* themselves. The lower, so called "*Regional appellation*", is not taken into account in the study, which starts at the ranking level of *Communes*, *Côte de Nuits* and *Côte de Beaune* AOCs and further up includes the *Premiers Crus* and the *Grands Crus*. The overall principle of Burgundy AOCs is that the higher you go in the ranking, the more precise the denomination of the site where the vine is cultivated (the smaller unit being the *climat*) and the wine produced. Small is beautiful. This is exactly opposite to the concept of brand.

It is not far from reasonable truth to state that the so chosen Y variables cover a range of wines that are all in taste and quality far above the average of the world production. Any of these wines is qualified "*vins de garde*", i.e. a wine that you usually wouldn't drink before several years after it has been bottled. In this paper, we have two analysis, one of the entire population of wines from the chosen area (*La Côte*), all ranks (*Commune* AOCs, *Premiers Crus* and *Grand Crus*) taken all together, and a second concerning only *Grands Crus*. But any finding, even concerning the most common

Communale AOC of “La Côte” could be used as a system of reference for any winery outside of Burgundy in search of excellence in the production of *terroir* wines.

The total picture of La Côte wines

Figure 1 – The total picture, components 1 & 2



The two first components map resulting from the analysis lays out the vineyards in three groups.

Groups 1 and 2 are stretched in an oval arrangement, parallel to landscape variables slope and altitude, both of these two showing strong correlation, which is natural, since steeper slope usually resides on higher reliefs in areas such as the concerned, with altitudes being comprised between 200 and 500 m.

Another, *minor* differentiation between group 1 and group 2 is orientation. Group 1, the *colluvium* group (see below) is more east facing, the other more south, which is correlated to the fact that colluvium, resulting from erosion has occurred in an west-east direction, more than north-south, reflecting the overall shape of the Côte. But there are exceptions, linked to the existing of west-east valleys and to the overall anticlinal-synclinal structure of the Côte.

Some would also argue that east facing vineyards benefit from the morning sun, which firstly leads to a faster removable of humidity accumulated on the soil and on the plants during the night and, secondly, permits to smoothen the day-night temperature differences limiting strain on the vine.

Anyway, orientation seems a minor factor when compared to the soil influence. And there is a catch, as far as colluvium is concerned, between having a good south facing plot of land, and having it on colluvium. At first sight, everyone, rather novice in vine cultivation would think that south is better, but, along the years and centuries of practice, the *vignerons* of Burgundy must have noticed that east facing slopes give frequently better results, because they correspond to a more appropriate soil. In other words, soil has precedence.

Group 1 vineyards are characterised by their main residing on a colluvium substratum. They are clearly separated from group 2 that can be identified primarily as residing on non colluvial calcareous soils, and dominantly compact limestone.

It is not fortuitous that both groups are so clearly distinguished. Colluvium is formed by accumulation of fallen, erosion broken, rocks at places where the slopes can retain them, hence, by definition they will not reside at the top of the reliefs, nor on steep slopes. And the principal components mapping shows that when considering slope and altitude variables, the dots representing vineyards of group 1 are situated on the low altitude side, in comparison to those belonging to group 2.

Group 2 is fully disjunct from group 1 and mainly structured along the compact limestone soil variable. However, in contrast to the colluvium group, some other soil variables are also at play. They all belong to the limestone family, whether porous, biodetritic or granular limestone.

There is a frequent misconception concerning the role of limestone as a soil and underground constituent for vineyards. For example, in a paper published in December 2002 by Lawrence D. Meinert and Alan J. Busacca of the Washington State University on the Red Mountain AVA (American Viticultural Area), we read the following:

“Although limestone is absent in the Red Mountain AVA, other than erratic boulders, the calcic-cemented gravel lenses form significant reservoirs of

calcium carbonate that can affect vineyard performance. For example, calcium is known to inhibit vine uptake of such essential nutrients as nitrogen and potassium (Winkler et al., 1974; Ribéra-Gayon et al. 2000). Also, Fe is particularly affected if water pools on calcic layers in the root zone (Sara Spayd written communication, 2002). Some Red Mountain wineries such as Terra Blanca, Spanish for white earth, point to these calcic layers as an important and sometimes negative part of the local terroir”.

Interesting to compare the complaint of these Red Mountain wineries with the pride of Clos-de-Vougeot *vignerons* to produce their *Grands Crus* on *Terre Blanche*, French for white earth.

The mechanism by which the *terroir* characteristics are transmitted to the vine and the grape has been explained by various scientists, such as Carbonneau, Lebon or Morlat. In this mechanism, *hydrification* – i.e. the way water is brought to the roots and consumed by the vine, or evacuated – plays a fundamental role. Roots require an excellent thermal and watering regulation, to avoid stress. Limestone, because of its ability to retain water, and possibly pump it from the underground and also because it acts as a temperature buffer (accumulating heat during the day and restoring part of it during the night) can play a very important role in this process. The same can be said about colluvium, albeit the process by which the watering is achieved might work in a different way. Compact limestone would primarily act as a sort of permanent sponge, pumping the water lying on a rather watertight bedrock. such as the “*Dalle Nacrée*” (pearly slab) covered by a layer of ferruginous oolite, and you will obtain *à grande échelle* what is achieved in some of the sophisticated flower pots. Colluvium will act differently. More than the sponge principle, the ability of the soil to store water, will play the major role. Therefore, the fact that colluvium is made of fragmented rocks leads to a different colonisation of the soil by the roots. In a compact limestone environment, the root will travel primarily in a vertical direction, using all the faults, crevices and rifts of the soil in its search for water. It will however find water, all along its way through, in contact with the porous rock. In a colluvium environment, roots will travel in all directions, surrounding, encircling, the fragmented pieces of rock, to literally “*suck*” the water from them. Granular or biodetritic limestone soils would act both ways depending upon the size of the fragments and the conditions in the bedrock.

When considering these factors, it is easy to understand why the irrigation of vineyards is prohibited in Burgundy, and why, in regions where this is authorised, like in the Napa Valley, the nature of the vineyards will be fundamentally different. A

Chardonnay from Puligny-Montrachet will taste differently from one from the Napa Valley. Moreover, it is likely that there will be more noticeable differences between a Chardonnay from Puligny-Montrachet and one from Meursault (albeit the vineyards they originate from are less than 5 km distant from each other), than between the Napa Valley Chardonnay and another from the Okanagan Valley (Canada) or even the Barossa Valley (Australia), that have grown with artificial irrigation, hiding most of the *terroir* incidence of the soil.

This also explains why it will be out of question to obtain a Burgundy AOC labelling before the vine is 30 years of age, because it is considered, that it takes all that time for the vine to establish its entire network of roots.

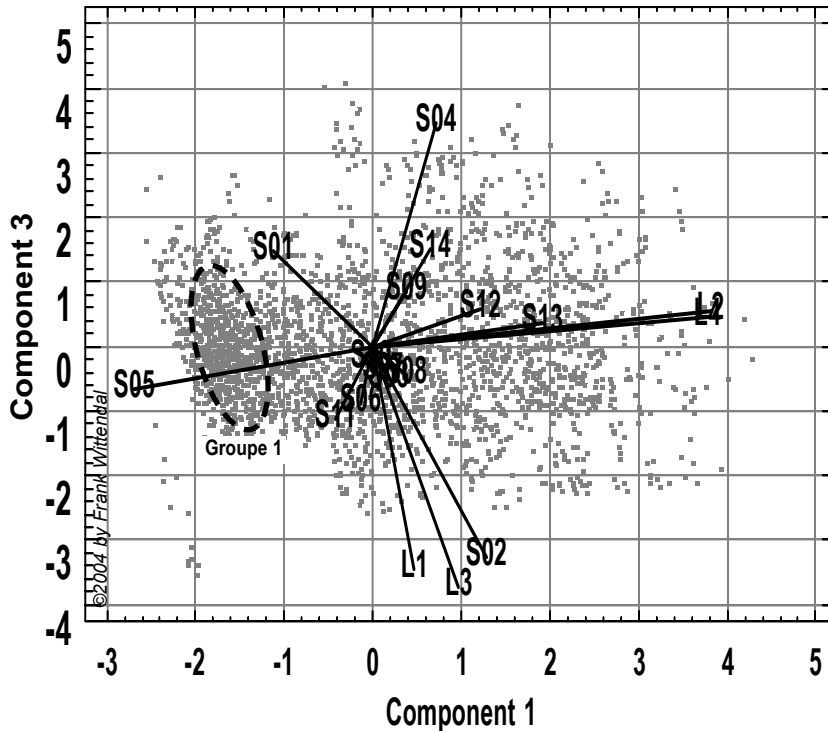
However, all these arguments do not entirely negate the idea that calcareous soils can play a negative role. All of this is a matter of levels. For example, clayey limestone with a CO₃ content between 80% and 90% is eliminated from the data set, once only *Grands Crus* are taken into account (see below).

Besides groups 1 and 2, the map shows a group 3 representing a dominant situation of vineyard sites on alluvial soils. Of course, there is no wonder that these soils are also situated at the low end of both altitude and slope indicators. Here you find most of the AOC *climats* of the south part of the Côte, i.e. Santenay, Meursault, Savigny, Beaune, including a Batard-Montrachet *Grand Cru*. But you find also a few Pommard *communale* AOCs (the Pommard *Premiers Crus* are on colluvium soils).

Components 1 and 3 biplot (figure 2) displays the information under another angle and illustrates the contradictory influences of landscape and soil. Altitude and slope are correlated and create an attraction in the cloud of dots towards the right hand side of the diagram. But there is another pole of attraction, just in the opposite direction, and this is represented by the colluvium variable. It is now more clearly seen that the soil characteristic has precedence, over altitude and slope, as the dot density (representing the population of vineyards) is higher on the left hand side of the chart (group 1).

East and south facing variables, now appear close together, but their influences seem not so important than these of soil variables. In addition, east-west orientation could be more or less summarised by the presence of compact limestone.

Figure 2 – The total picture, components 1 & 3

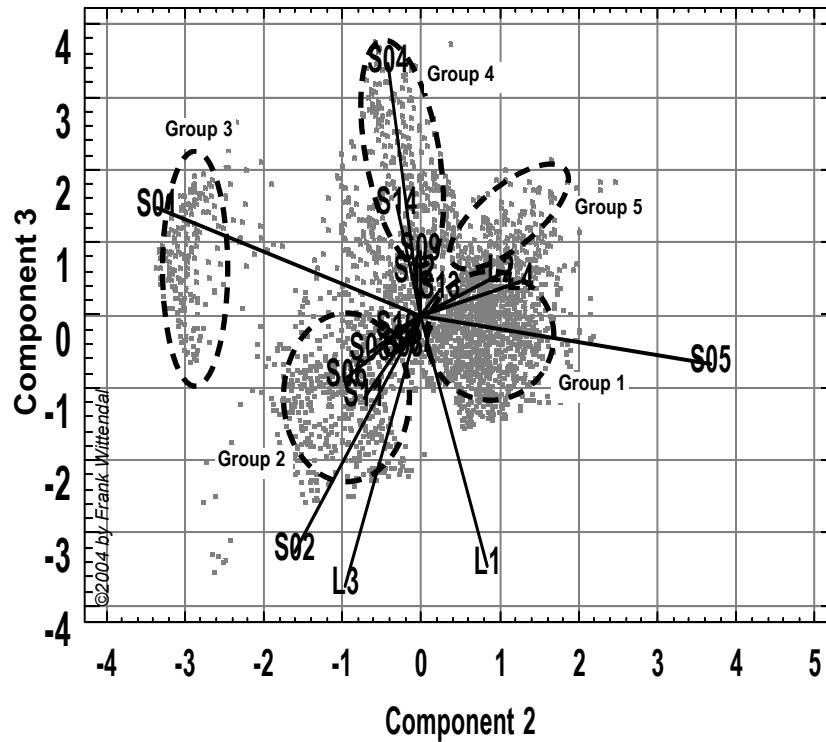


Finally, the components 1-3 plot opposes the landscape segment, altogether more or less summarised by compact limestone, to the soil segment where colluvium, granular limestone and alluvial deposits are the main driving forces. In colluvium, we are in the favourite soil for Volnays, including a few in *Premiers Crus*, such as *Clos des Chêne*, *les Caillerets*, *Au Mitan*, *Les Carrelles*... (delicate red wines, transparent, rubis dress). Not far from there, you find Monthélie, and Pommard *Premiers Crus*. But this is no exclusivity. The colluvium substratum is to be found in many other *climats* throughout Burgundy, including Gevrey-Chambertin, Auxey-Duresse, Corton, Fixin, etc.

Components 2 and 3 plot (figure 3) confirms that on the side of soil the four most relevant soil variables are colluvium, and the two forms of limestone (compact, granular) and alluvial deposits. Again slope and altitude are in proximity to compact limestone.

This view also incites to rearrange all the vineyards in 5 groups, with group 3 being quite individualised on granular limestone. Indeed this is a rather specific feature of the white wine from the south of the *Côte*. In this group, you will find many *climats* in Chassagne-Montrachet, Saint Aubin, Santenay, Meursault...

Figure 3 – The total picture, components 2 & 3



Technical information on the analysis

Table 2 (Principal Components Weights) shows the equations of the principal components. For example, the first principal component has the equation:

$$\begin{aligned}
 &0.0671826*L1 + 0.559467*L2 + 0.141856*L3 + 0.551467*L4 - 0.164465*S01 \\
 &+ 0.187343*S02 + 0.0254542*S03 + 0.104603*S04 - 0.39219*S05 \\
 &- 0.0195934*S06 + 0.0166115*S07 + 0.0550893*S08 + 0.0558035*S09 \\
 &- 0.00333501*S10 - 0.0614129*S11 + 0.178744*S12 + 0.281275*S13 \\
 &+ 0.0950759*S14
 \end{aligned}$$

where the values of the variables in the equation are standardised by subtracting their means and dividing by their standard deviations.

Table 2 – Component Weights

	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6	Component 7
L1	0.0671826	0.14292	-0.452944	0.333204	0.250627	0.0479313	-0.094782
L2	0.559467	0.174648	0.0730978	-0.050319	-0.088981	0.0459761	0.0045783
L3	0.141856	-0.165894	-0.492582	0.046058	-0.139761	0.0878384	-0.02907
L4	0.551467	0.21609	0.0586592	-0.048984	0.0489115	-0.035476	0.0329255
S01	-0.164465	-0.575122	0.193757	0.138291	-0.284592	0.0017876	0.189474
S02	0.187343	-0.277049	-0.428107	-0.626418	0.017828	-0.240544	0.0491239
S03	0.0254542	-0.110858	-0.066652	0.131142	0.164482	0.0862788	-0.153373
S04	0.104603	-0.073661	0.456506	-0.177494	0.209939	-0.100585	-0.630513
S05	-0.39219	0.631356	-0.087893	-0.096238	-0.104346	-0.000373	0.0270795
S06	-0.019593	-0.162358	-0.114566	0.193758	0.139754	0.128541	-0.260704
S07	0.0166115	-0.017066	-0.052359	0.0625121	0.0373748	0.0540837	-0.057339
S08	0.0550893	-0.0403	-0.058918	0.159897	0.287109	0.0573236	-0.13383
S09	0.0558035	-0.000836	0.11433	-0.044054	-0.022683	0.0354758	0.0334709
S10	-0.003335	-0.054452	-0.026408	0.0962222	0.142378	0.0108374	-0.072633
S11	-0.061413	-0.123145	-0.149097	0.209638	0.201323	0.0357588	-0.182354
S12	0.178744	-0.014338	0.0740733	-0.02462	-0.196019	0.844548	0.074203
S13	0.281275	0.0413344	0.0455062	0.530538	-0.406245	-0.412726	0.0327396
S14	0.0950759	-0.051846	0.197848	0.0905185	0.613091	-0.046859	0.627342

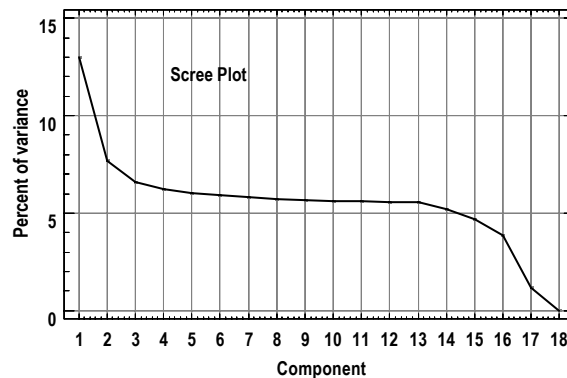
	Component 8	Component 9	Component 10	Component 11	Component 12	Component 13
L1	-0.019586	-0.052798	0.0781607	0.0273856	-0.00565	0.0281631
L2	-0.024697	0.0041361	-0.023613	0.0226999	-0.007922	0.0148811
L3	0.0287287	0.0381057	0.0111806	-0.075273	-0.021678	0.0274307
L4	0.0464421	-0.011144	-0.011998	-0.023275	0.0112908	-0.006186
S01	0.100784	-0.132581	0.0018755	-0.034651	0.0012086	0.0591627
S02	-0.043574	-0.031011	0.0361361	0.0230796	0.0079373	-0.026008
S03	0.643895	0.646559	-0.119145	-0.000418	-0.004157	-0.026136
S04	-0.053148	0.0020761	0.180511	-0.107011	-0.042577	0.0371833
S05	0.0121216	0.0034035	-0.007734	-0.025295	-0.004938	0.0083297
S06	-0.614169	0.218672	-0.506412	-0.180443	0.0509732	-0.052327
S07	-0.036738	-0.018822	0.065568	0.112056	-0.121967	0.958802
S08	0.383076	-0.697669	-0.352292	-0.125349	-0.046369	-0.050529
S09	-0.027073	0.0091874	-0.419724	0.835777	-0.184894	-0.056426
S10	-0.020167	-0.067971	0.190453	0.324676	0.886084	0.0191345
S11	-0.130811	-0.066845	0.558463	0.319811	-0.394531	-0.239374
S12	-0.040047	-0.041596	0.163796	-0.043937	0.014359	-0.063892
S13	-0.053143	0.0195242	0.0667671	-0.025847	-0.000445	-0.04372
S14	-0.135703	0.113256	0.0666696	-0.095177	-0.050734	0.0211262

Table 3 – Summary of Analysis

Component Number	Eigenvalue	Percent of Variance	Cumulative Percentage
1	2.33988	12.999	12.999
2	1.37789	7.655	20.654
3	1.19035	6.613	27.267
4	1.1242	6.246	33.513
5	1.08503	6.028	39.541
6	1.07003	5.945	45.485
7	1.04898	5.828	51.313
8	1.02502	5.695	57.008
9	1.02315	5.684	62.692
10	1.01505	5.639	68.331
11	1.01001	5.611	73.942
12	1.00547	5.586	79.528
13	1.00298	5.572	85.1
14	0.934543	5.192	90.292
15	0.840629	4.67	94.962
16	0.693538	3.853	98.815
17	0.21325	1.185	100
18	0	0	100

The purpose of the principal components analysis is to obtain a small number of linear combinations of the 18 variables which account for most of the variability in the data. In this case, 13 components have been extracted, since these components had eigenvalues greater than or equal to 1.0. Together they account for 85.1% of the variability in the original data.

The “*scree plot*” (figure 3) shows that from a practical view point only the 3 first components are useful for the purpose of our investigation.

Figure 4 – Contribution of components (% of data variance)

The Grands Crus picture

Figure 5 – Red Grands Crus positions, within the total picture, components 2 & 3

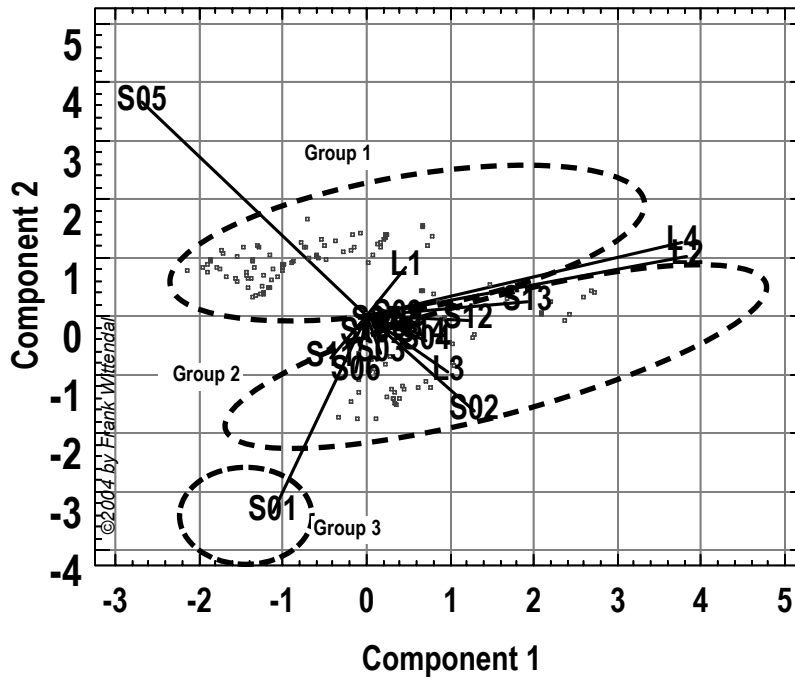
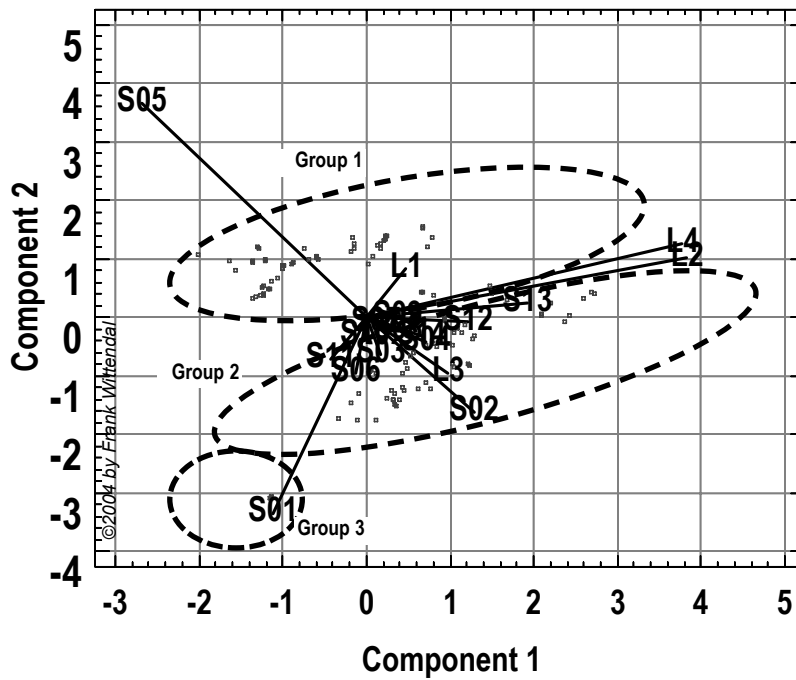


Figure 6 – White Grands Crus positions, within the total picture, components 2 & 3



Figures 5 and 6 map the *Grands Crus* vineyards within the set of principal components defined by the principal components analysis on *all* the *Côte* vineyards. Hence, the components are the same and the position of the X variables are identical to these of displayed in “*The total picture of La Côte wines*”, figure 1, above.

There are some differences in the way the dots are dispatched in the diagrams.

Concerning red *Grands Crus*:

The group 3 of figure 1 is non existent. In other words, we have no red *Grands Crus* on alluvial soils.

In group 2 we see that the dots are now more concentrated towards the centre of the diagram.

In group 1 the dots are all closer to the colluvium variable.

Concerning white *Grands Crus*:

In group 3, we have now only one *climat* (a Batard-Montrachet).

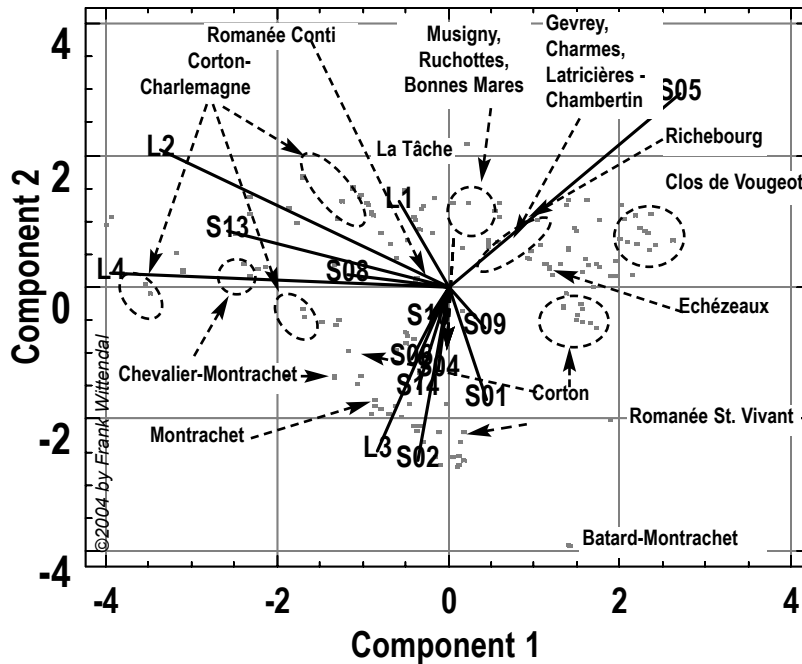
Concerning group 2 and 3 same remarks as for red *Grands Crus*.

In truth, there has been a movement of the vineyards towards the centre, but still we can distinguish, within the *Grands Crus* category, the three groups we had in the entire population, the alluvial group being now reduced to one vineyard.

Let's now run the principal components analysis on the *Grands Crus* vineyards only (there are 156 vineyards composing 33 AOC denominated *Grands Crus* in the data base), and see what happens (figure 8).

First of all, the analysis drops three X variables that are absent when taking only *Grands Crus* into account: sandy marl, clay with silicate sand and clayey limestone. First conclusion: no *Grands crus* on siliceous soils, even when mixed with limestone as defined by clayey limestone with a C03 content of between 80% and 90%. There are however *Grands Crus climats* on marl (C03 content of between 33% and 66%), for example in the Corton-Charlemagne AOC.

Figure 8 – The Grands Crus picture components 1 & 2



Secondly, the analysis entirely redraws the components system. The concentration of the *Grands Crus* closer to the centre of the original principal components plots, and the disappearing of 3 variables now lead to more precision in the diagram, namely:

Concerning landscape variables, a better distinction between altitude and slope and more contrast between east and south facing influences.

Concerning soil influences, we now have three main directions: colluvium, compact limestone and marl. And the relevance of marl appears to be quite specific in the description of *Grands Crus* vineyards relatively to what we had concerning the entire population.

Figure 8 is an attempt to identify most of the *Côte Grands Crus* within their two first components plot. Some of them are undubitably within one group, for example the Clos-de-Vougeot, and Chambertin *Grands Crus* are entirely characterised by a dominance of colluvium.

The *Grands Crus* AOCs applicable only to one *climat*, formed of contiguous small parcels such as Richebourg, La Tâche, etc, are of

course also identified by only one position in the diagram.

But it is somewhat different, when considering *Grands Crus* applying to a set of non contiguous parcels, such as Corton, Corton-Charlemagne, or Chevalier-Montrachet.

This translates the specifics of Corton *Grands Crus*, as being placed rather in a semi circular arena situated on the west-south-east slopes of the Corton *Mountain*. This explains the variability in exposition, but still with a south dominance, and in soils. The *terroir* unity must therefore result in part from the *savoir faire* of *vignerons*; and this may explain why there is no reference to the *climat* name in the Corton-Charlemagne *Grand Cru* AOC, and why this is optional in the Corton *Grand Cru*.

For further understanding these differences, figures 9 and 10 compare two situations, in red *Grand Cru*, that of Clos-de-Vougeot, with a concentration of the *climats*, and that of Corton with dispersion.

Figures 11 and 12 shows the same dissimilarity between Chevalier-Montrachet and Corton-Charlemagne, but still with a Chevalier-Montrachet being somewhat dispersed in terms of slope and orientation.

Finally, figures 13 and 14 compare the positions of white and red *Grands Crus*, within the two first components established when taking all *Grands Crus* (red and white).

White *Grands Crus* (Corton-Charlemagne, Montrachet, Batard-Montrachet, Bienvenues-Bâtard-Montrachet, Chevalier-Montrachet and Criôts-Bâtard-Montrachet) are dominantly on the left hand side of the diagram, in the direction of altitude and slope, with, in these situations, marl playing an important role as a soil. But there are still some white *Grands Crus* on the right hand side, basically situated on colluvium.

Concerning red *Grands Crus*, altitude and slope play a minor role (this is all in relative terms, as we speak of standardised variables). Their main driving forces are the soil, firstly colluvium, secondly limestone, and the east orientation..

Figure 9 – Clos-de-Vougeot Appellation, 2 First Components Map

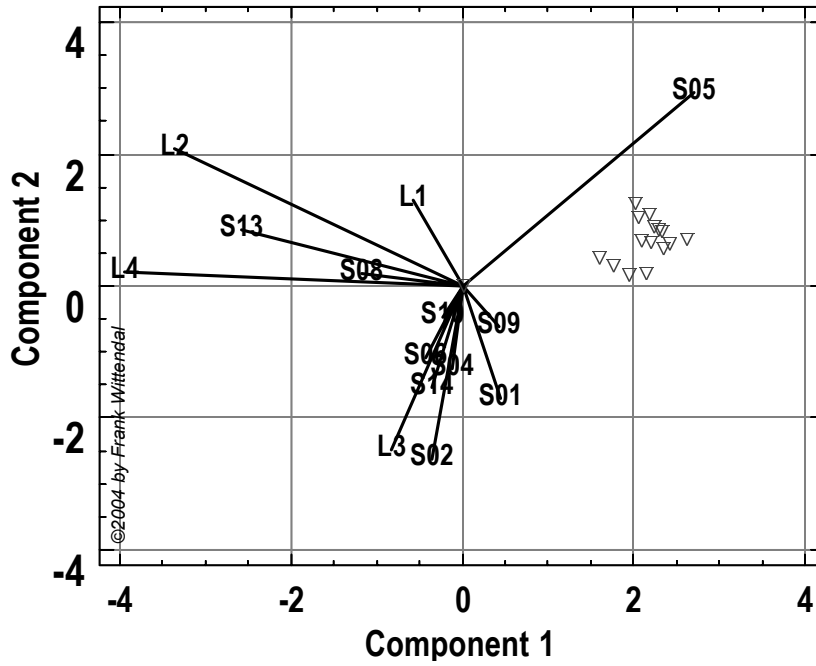


Figure 10 – Corton Appellation, 2 First Components Map

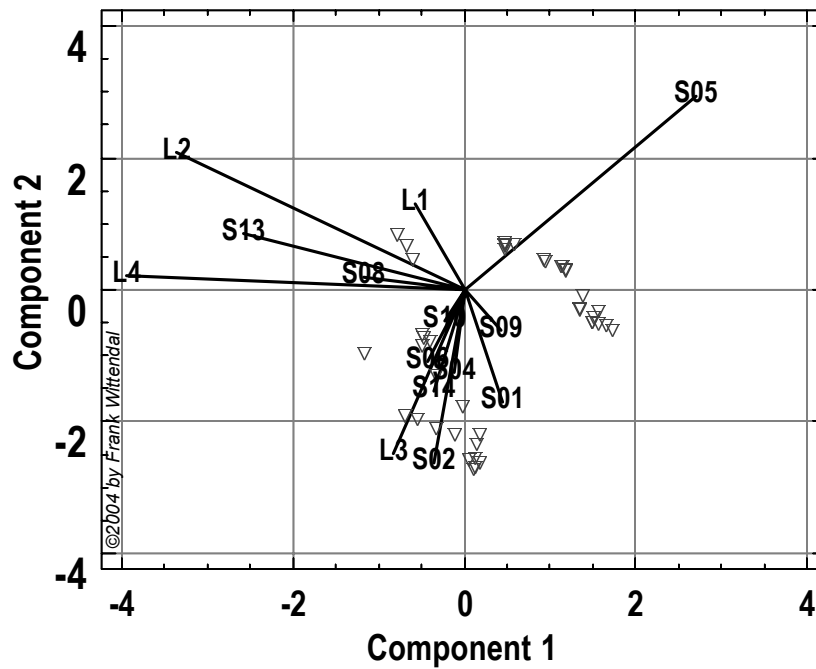


Figure 11 – Corton-Charlemagne Appellation, 2 First Components Map

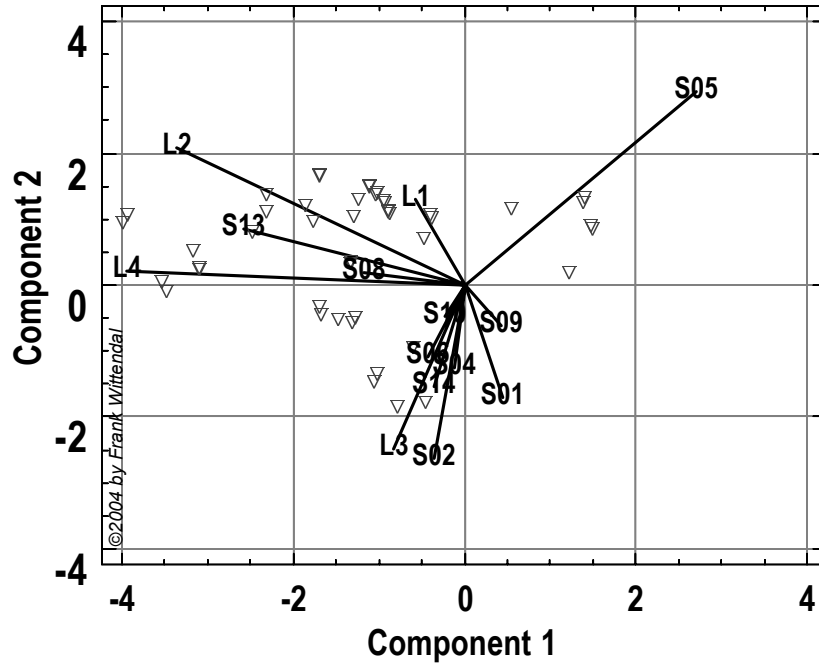


Figure 12 – Chevalier-Montrachet Appellation, 2 First Components Map

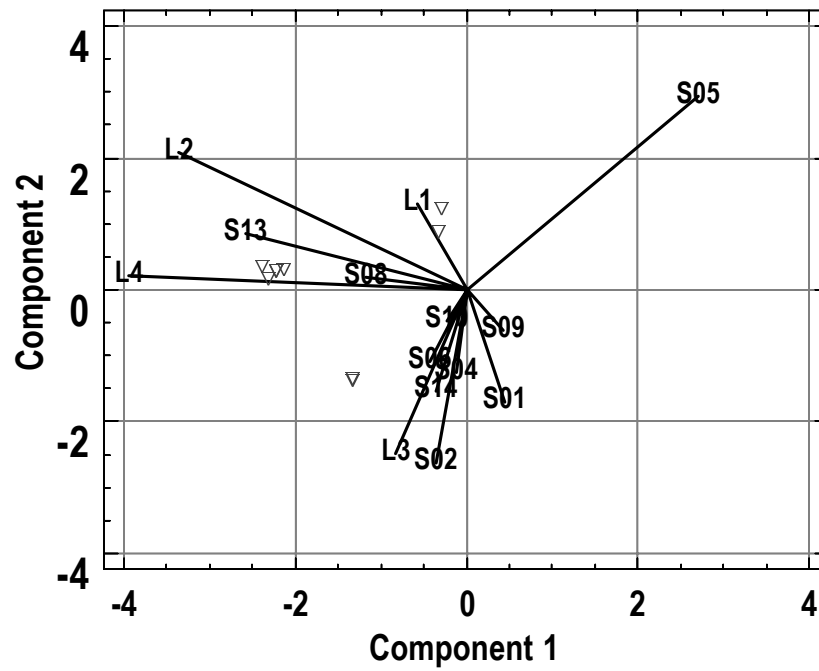


Figure 13 – Burgundy White Wines: *Grands Crus*, 2 First Components Map

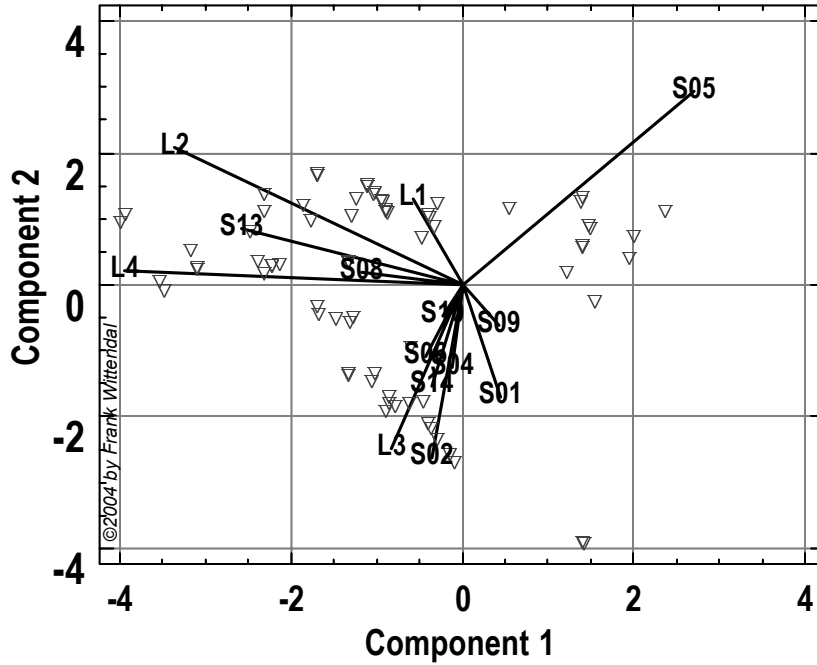
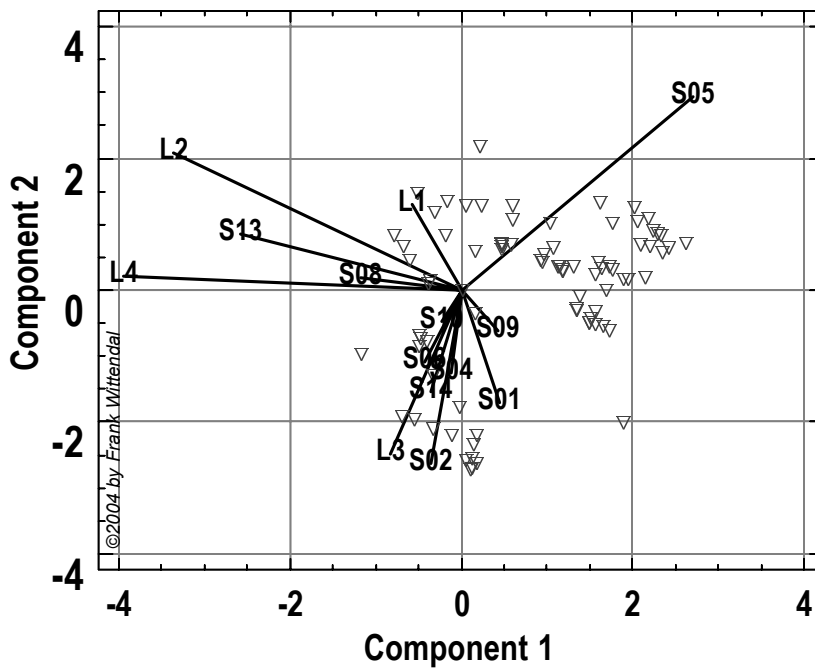


Figure 14 – Burgundy Red Wines: *Grands Crus*, 2 First Components Map



Technical information on the analysis

Table 4 (Principal components Weights) shows the equations of the principal components. For example, the first principal component has the equation:

$$\begin{aligned}
 & -0.053195*S14 - 0.388905*S13 - 0.0330027*S10 + 0.0648303*S09 \\
 & -0.175634*S08 - 0.0647756*S06 + 0.406344*S05 - 0.0178382*S04 \\
 & -0.0522355*S02 - 0.0865762*L1 - 0.506881*L2 - 0.123553*L3 \\
 & - 0.594222*L4 + 0.0680913*S01
 \end{aligned}$$

where the values of the variables in the equation are standardised by subtracting their means and dividing by their standard deviations.

Table 4 – Component Weights

	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6	Component 7
S14	-0.053195	-0.252398	-0.433137	0.201634	-0.251239	-0.262687	-0.432129
S13	-0.388905	0.139424	0.281544	-0.306742	-0.31667	-0.338916	0.0153694
S10	-0.0330027	-0.0774066	-0.336835	-0.334307	-0.236043	0.201487	-0.0739724
S09	0.0648303	-0.101651	0.0501833	-0.294474	-0.271963	0.0815049	0.0905124
S08	-0.175634	0.0316343	-0.319424	-0.0734412	0.278062	0.434561	0.452886
S06	-0.0647756	-0.177621	0.274006	0.165744	-0.223335	0.725516	-0.316859
S05	0.406344	0.480928	-0.0104936	0.373019	0.134512	-0.0649509	-0.0057148
S04	-0.0178382	-0.207238	-0.0567712	0.145756	-0.103976	-0.0665354	0.521234
S02	-0.0522355	-0.430396	0.107814	-0.270972	0.662858	-0.147659	-0.170871
L1	-0.0865762	0.214409	-0.618645	-0.155725	-0.0331862	0.0036301	-0.0258599
L2	-0.506881	0.342564	0.0898113	0.229818	0.008161	0.0171902	-0.0274139
L3	-0.123553	-0.40677	-0.150541	0.525338	-0.0053167	-0.0759619	0.0104742
L4	-0.594222	0.0365371	-0.0146438	0.178801	0.157673	-0.008311	0.0138379
S01	0.0680913	-0.279971	0.106848	0.122808	-0.292197	-0.13068	0.43729
	Component 8	Component 9					
S14	0.297558	-0.140284					
S13	0.0206586	0.0044483					
S10	-0.556056	0.329009					
S09	0.422626	-0.41736					
S08	0.397483	0.047094					
S06	-0.0383282	-0.0520269					
S05	-0.0371649	0.0265841					
S04	-0.462846	-0.568305					
S02	-0.0512563	0.0266962					
L1	-0.0055177	-0.0082987					
L2	-0.0271513	0.0236042					
L3	-0.0517569	0.0497869					
L4	-0.0254366	0.0104671					
S01	0.203546	0.604429					

Table 5 – Summary of Analysis

Number	Eigenvalue	Percent of Cumulative	
		Variance	Percentage
1	2.34993	16.785	16.785
2	1.59703	11.407	28.193
3	1.33632	9.545	37.738
4	1.17063	8.362	46.099
5	1.09365	7.812	53.911
6	1.05883	7.563	61.474
7	1.03057	7.361	68.835
8	1.02272	7.305	76.141
9	1.01605	7.257	83.398
10	0.943622	6.74	90.138
11	0.699392	4.996	95.134
12	0.565501	4.039	99.173
13	0.0840012	0.6	99.773
14	0.0317635	0.227	100

The purpose of the principal components analysis is to obtain a small number of linear combinations of the 14 variables which account for most of the variability in the data. In this case, 9 components have been extracted, since 9 components had eigenvalues greater than or equal to 1.0. Together they account for 83.398% of the variability in the original data.

The “*scree plot*” (figure 15) shows that from a practical view point only the 3 first components are usefull for the purpose of our investigation.

Figure 15 – Contribution of components (% of data variance)

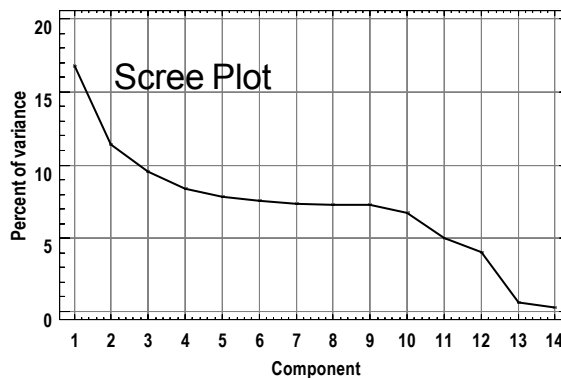


Table 6 – Alphabetical List of Burgundy “Grands Crus”

Bâtard-Montrachet
Bienvenues-Bâtard-Montrachet
Bonnes-Mares
* Chablis Grand Cru
Chambertin
Chambertin-Clos de Bèze
Chapelle-Chambertin
Charlemagne
Charmes-Chambertin
Chevalier-Montrachet
Clos de la Roche
Clos de Tart
Clos de Vougeot
Clos des Lambrays
Clos Saint Denis
Corton
Corton-Charlemagne
Criots-Bâtard-Montrachet
Échezeaux
Grands Échezeaux
Griotte-Chambertin
La Grande Rue
La Romanée
La Tâche
Laticières-Chambertin
Mazis-Chambertin
Mazoyères-Chambertin
Montrachet
Muscigny
Richebourg
Romanée-Conti
Romanée-Saint-Vivant
Ruchottes-Chambertin

* Not in study (vineyards of Chablisien).

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