AIG Journal

Published by the Australian Institute of Geoscientists
ISSN 1443-1017

Wine, vine and rocks – how does it work?

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Introduction

Australia is host to some of the oldest rocks on Earth, with zircons from Jack Hills in Western Australia dated over 4 billion years (Valley et al. 2014). The equivalent of these zircons in the world of wine are pre-phylloxera grape vines, before the phylloxera – a sap-sucking insect – devastated vineyards in Europe and other parts of the world in the late 19th century. Australia was only affected in a limited way and is now believed to host among the oldest vines in the world, shiraz vines planted back in 1843 in South Australia.

The wide range of climates and geological formations in Australia defines unique viticultural regions, ranging from cool climate Tasmania to the warmer Hunter Valley in New South Wales. If climate is believed to be the number one influencing factor in growing vines (van Leeuwen et al. 2004), geology is often quoted as a key component of the 'terroir', along with soil and topography. This article looks at wine regions in Australia, and across the world, to explore the relationship between geology and wine.

Geology and Vine

Grape vines typically develop the majority of their roots within the top 60 cm with a fraction extending several metres deep. The soil is therefore commonly the interface between the underlying bedrock and the vine, and the nature of the bedrock is key in developing a suitable viticultural site. Soil characteristics contribute to vine development via influence on water availability, nutrient composition and availability, and mechanical resistance to root penetration.

For instance, the development of the Terra Rossa soils in the Coonawarra wine region in South Australia is the result of a combination of geological events that gave birth to the 25km-long and 2km-wide Penola Land System along the Limestone Coast (Figure 1). The Penola Land System overlies the beach to aeolian calcarenitic dunes of the Bridgewater Formation (Morand et al. 2003) and the carbonates and clays of the Padthaway Formation which developed as swamps between the dunes of the Bridgewater Formation. The two geological units developed during the glacial cycles of the Pleistocene. Sea retreat later exposed the carbonates to erosion and dissolution, and resulted in the formation of an extensive calcrete horizon atop porous carbonate formations. The Terra Rossa is believed to be of aeolian origin, comprised of red sandy loam and clay loam (red dermosol), mostly deposited 130 – 150,000 years ago (Mee et al. 2004) on the calcrete horizon. A thicker calcrete in the Penola Land System allowed a better preservation in the form of a low rise in the landscape (Figure 1) and likely contributed to a further oxidation of the wind-blown iron oxides giving the Terra Rossa its name. These soils are characterised by a low water holding capacity, good drainage and aeration, and high calcium content, creating an adequate substrate for vines, and Cabernet Sauvignon in particular (Longbottom, Maschmedt & Pichler 2011).

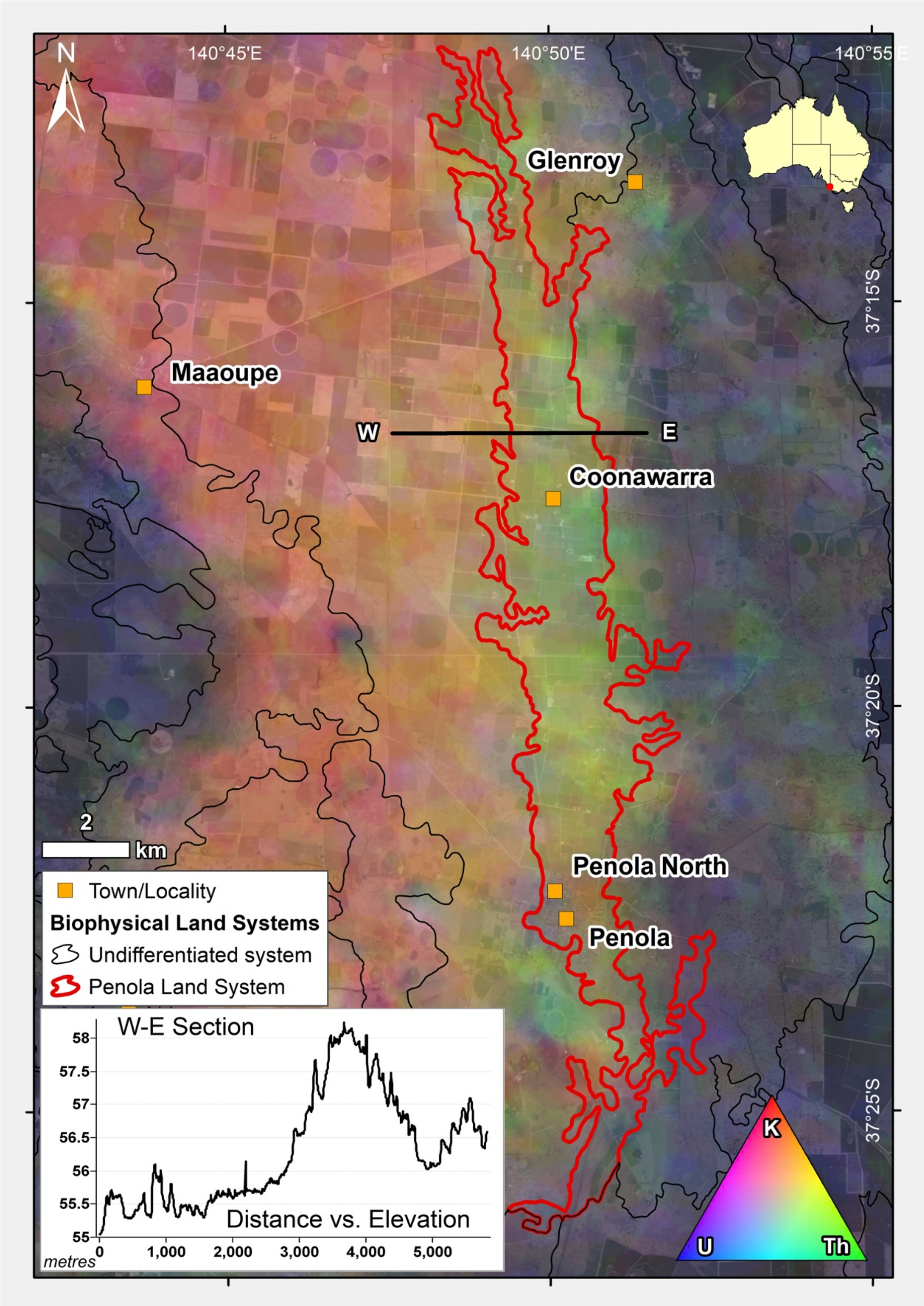

Figure 1. Location and radiometric signature of the Penola Land System in the Coonawarra wine region in South Australia. Topographic profile derived from 5m-grid Digital Elevation Model (LiDAR, 2017, Geoscience Australia). Penola Land System limits obtained from the Department of Environment, Water and Natural Resources of South Australia. Ternary K, U, Th image obtained from Department of Primary Industries and Resources, South Australia. The Terra Rossa soils are characterised by a high thorium, low potassium-uranium radiometric signature.

As a general rule, clay-dominated soils are known for good water retention and poor drainage as well as for preventing deep root penetration. In contrast, the prevalence of sands in a soil ensures good drainage and heat retention. The type of clays, and their inherent ability to retain the cations needed by the vine, is key to vineyard quality. Soil scientist Claude Bourguignon studied in 2015 the specific surface area (SSA) of the clay component of three vineyards in Burgundy (France), along the slope of the Montrachet hill (Bourguignon 2015). The Montrachet hill in cool-climate Burgundy produces internationally acclaimed chardonnay wines and the world-famous Montrachet. The Grand Cru vineyard (first-tier plot) of Montrachet showed a lower SSA than Premier Cru vineyard Clavoillon (second-tier plot) with Village vineyards (Les Houillères, third tier) showing the highest SSA. These three vineyards lie within 750 m of each other and are underlain by distinct combinations of lithologies (Figure 2). The westernmost Montrachet is comprised of scree overlying Bathonian oolithe and massive limestone whereas Clavoillon is only comprised of scree and massive limestone. Les Houillères lies on recent colluvium. The SSA is closely related to the capacity of a soil to hold exchangeable cations essential to the vine such as potassium, calcium, magnesium, iron or manganese. Therefore, the high SSA associated with recent colluvium translates in an abundance of nutrients adsorbed on clays and organic matter and potentially available for the vine. This will in turn favour intense vegetative growth with extensive canopy and new shoots at the expense of fruit quality. In contrast, when faced with a scarcity of nutrients associated with a low SSA developed on limestone, the vine will tend to favour production of a limited number of grape clusters concentrating flavours and sugar and resulting in more complex wines.

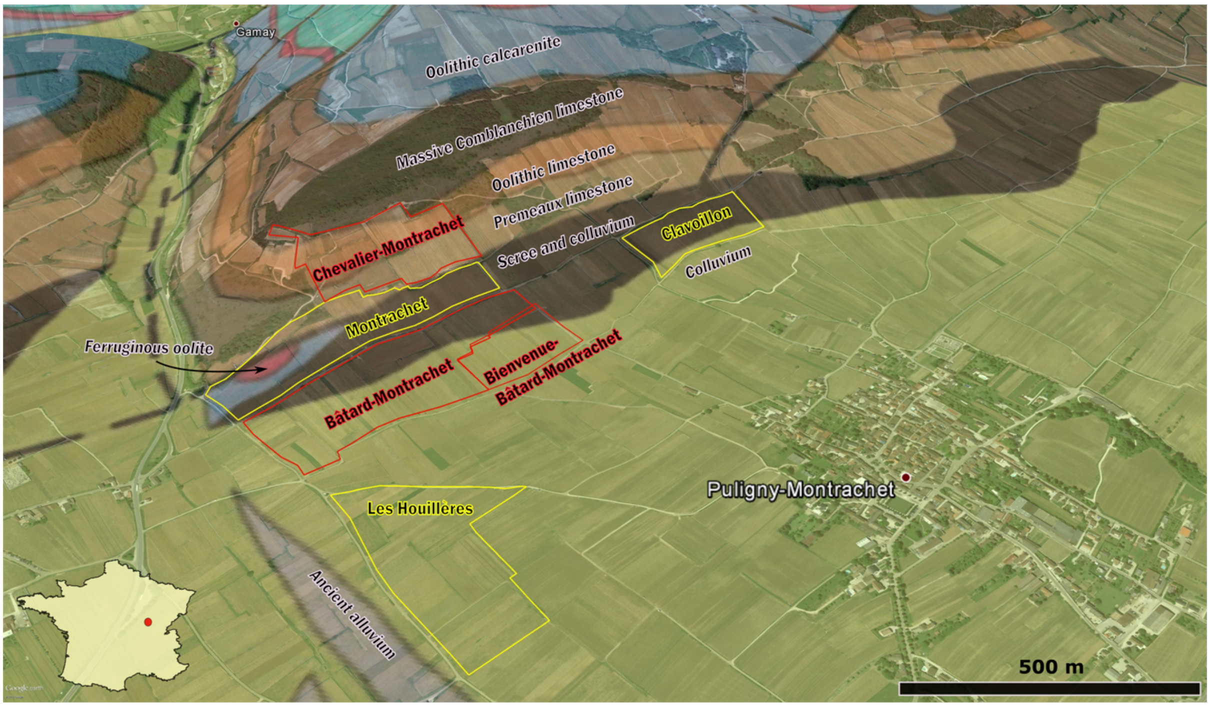

Figure 2. 3D view of the Montrachet hill looking NNW showing the location and geology of the Montrachet, Clavoillon and Les Houillères plots near the village of Puligny-Montrachet in southern Burgundy, France. Geological formations and corresponding descriptions obtained from the French Geological Survey (Bureau de Recherches Géologiques et Minières, BRGM). Plot boundaries digitised from maps produced by the Bourgogne Wine Board (www.bourgogne-wines.com)

Geology and Wine

The previous examples illustrate the impact of geological processes and lithologies on soil formation and on the suitability of a site to become a great vineyard. However, is it realistic to say that a wine tastes of the underlying rocks?

Crisp white wines are sometimes described as having a distinct ‘minerality’, with descriptors derived from a geological lexicon: mineral, slaty, chalky, stony or having gunflint, silex or wet stone aromas. The general consensus is that a direct link has yet to be determined between the geological formations and the taste of a wine. Such a link has even been dismissed as a “romantic notion” and a “powerful marketing tactic” (Maltman 2008). A sensory and chemical analysis on Burgundy chardonnay (Chablis, region known for the minerality of its wines) was conducted in 2017 and concluded that minerality was correlated with descriptors such as gunflint, sulphur and wood and a lack of fruity character (Rodrigues et al. 2017). It was also correlated with the presence of the sulphur-containing compound methanethiol involved in shellfish/chalky character. The study argues these characters are in part controlled by the position of the vineyards with regard to a local river (left bank wines had a more pronounced minerality). Given that all the wines in the study were made from vines planted on the same Kimmeridgian limestone and marl formation, this argues for a minor role, if any, of geology in the mineral character of a wine.

If scientific studies seem to dismiss a direct link between geology and specific wine flavours, trends have been observed in wine regions where single vineyard wines derived from small plots of relatively homogeneous geology have been crafted for centuries. In the region of Barolo (Piedmont, Italy), vineyards are traditionally described according to the geological formation they are planted on as soil development is limited by intense erosion. Moreover, the Barolo denomination is restricted to a single red grape variety, nebbiolo. This makes for a unique opportunity: a single grape variety rooted on thin soils developed over different geological formations. The vineyards around the village of Serralunga d’Alba, east of Barolo, consist of the calcareous marls of the Middle Miocene Lequio Formation and show the highest calcium carbonate content in the Barolo area (28.9 % $CaCO_3$ for Serralunga). Wines from Serralunga are generally perceived as more powerful and as showing a strong tannic structure, typical of Barolo wines (O’Keefe 2014). The soils of La Morra – one of the highest-prized sub-regions of Barolo – consist of bluish-grey marls of the Sant’Agata Fossili formation of Upper Miocene age (Soster & Cellino 2000). They boast the highest clay content among the sub-regions of Barolo. The wines from La Morra are often described as more elegant and perfumed and having more finesse than those from other parts of Barolo. It is however important to keep in mind that the winemaker’s choices may have a significant influence on wine structure (maceration, use of new or aged oak barrels, etc.).

Geology sometimes also affects the winemaker’s decisions in the cellar. As an example, in the Paarl region in South Africa (Western Cape), young soils derived from potassium-rich granites of the Cape Granite Suite have been shown to increase the potassium content of the must (Bargmann 2003). An increased potassium content leads to an increase in pH, as potassium reacts with the most common organic acid in ripe grapes, tartaric acid, and precipitates as potassium bitartrate crystals. The pH of the must is an important parameter as it controls colour stability, sulphur dioxide effectiveness and whether bacteria are likely to develop or not.

This seems to suggest that geology may have an indirect influence on wine balance and structure. If this is true, would complexity in the geological context impart complexity to the wine? A complex geological setting is often ascribed to intense structural deformation and faulting.

Faults and vineyard complexity

Among the wine regions of the world, several are established in fault-controlled geological settings, among which the Santa Cruz Mountain appellation (San Andreas Fault, USA), Hawke's Bay and Martinborough in New Zealand or Heathcote in Australia (McCoy 2016). In theory, the presence of faults creates a juxtaposition of various lithologies across short distances hence allowing vines in a same vineyard to grow on varying soil types, resulting in more complex wines.

Faulting and regional tectonics also tend to influence the slope and exposure of vineyards, potentially defining more favourable climatic conditions which in turn allow better ripening conditions or protection from extreme weather, such as in the McLaren Vale in South Australia.

The McLaren Vale extends from the Willunga Escarpment in the east to the St Vincent Gulf (Figure 3) and encompasses a section of the Neoproterozoic to Cambrian Mount Lofty Ranges, deformed around 500 Ma ago (Delamerian Orogeny). The region is dissected by two NE-striking faults (Figure 3), developed as normal faults during the Eocene-Miocene and re-activated as reverse faults during the Pleistocene, and still active today: the major Willunga Fault to the SE and the Ochre Cove-Clarendon Fault to the NW (Tokarev 2005). The down-thrown compartment between the Willunga Fault and the Mount Lofty Ranges defines the Willunga Embayment while the Noarlunga Embayment corresponds to the foot wall of the Ochre-Cove – Clarendon Fault further to the north. The two embayments are filled with Eocene to Holocene clastic and carbonate sediments. This geological configuration provides a variety of soils from the Pleistocene piedmont sediments at the foot of the Willunga Escarpment to Neoproterozoic sandstones and carbonates on the Ranges. This variety is reflected in the 19 wine districts which have been distinguished in the region based on soil, geology and meso-climate (McLaren Vale Grape Wine and Tourism Association 2013).

In the McLaren Vale, the topography and distance to the ocean are crucial parameters to understand ripening conditions. The rainfalls are controlled by the distance to the Willunga Escarpment, close to which annual rainfall amounts to 800 mm for about 500 mm near the ocean. The relative uplift of the Mount Lofty Ranges also generates the formation of 'gully' or orographic winds flowing east-west, down from the Ranges, and accompanied by typical 'range cloud'. The cloud and wind favour a slower ripening in the summer months whereas the wind specifically helps with drying of vineyard canopies and ensures cold air does not settle overnight in the spring, hence preventing frost damage (Skinner 2015). Summer afternoon sea breezes also control diurnal variations, smoothing variations for vineyards located closer to the coast.

Further to locally offering a beneficial impact on climatic and ripening parameters, the presence of faults is known to be associated with some of the best and most complex wines in the world. A region sometimes described as a mosaic of terroirs illustrates this relationship perfectly: Alsace in France.

Alsace lies on the western part of the NNE-trending Upper Rhine Graben, developed from the Eocene to the Oligocene. The western margin of the graben is delineated by the regional Vosges Fault and is associated with local dense networks of faults termed 'fault fields'. The fault fields result of repeatedly changing stress fields and reactivation of older Permo-Carboniferous crustal-scale structures (Schumacher 2002). Near the village of Ribeauvillé, a complex network of faults delimits a multitude of compartments (Figure 4), in the form of horsts and grabens, resulting in the juxtaposition of blocks of Carboniferous, Triassic, Jurassic and Paleogene volcanics and sediments within very short distances (typically 100 m – 1 km).

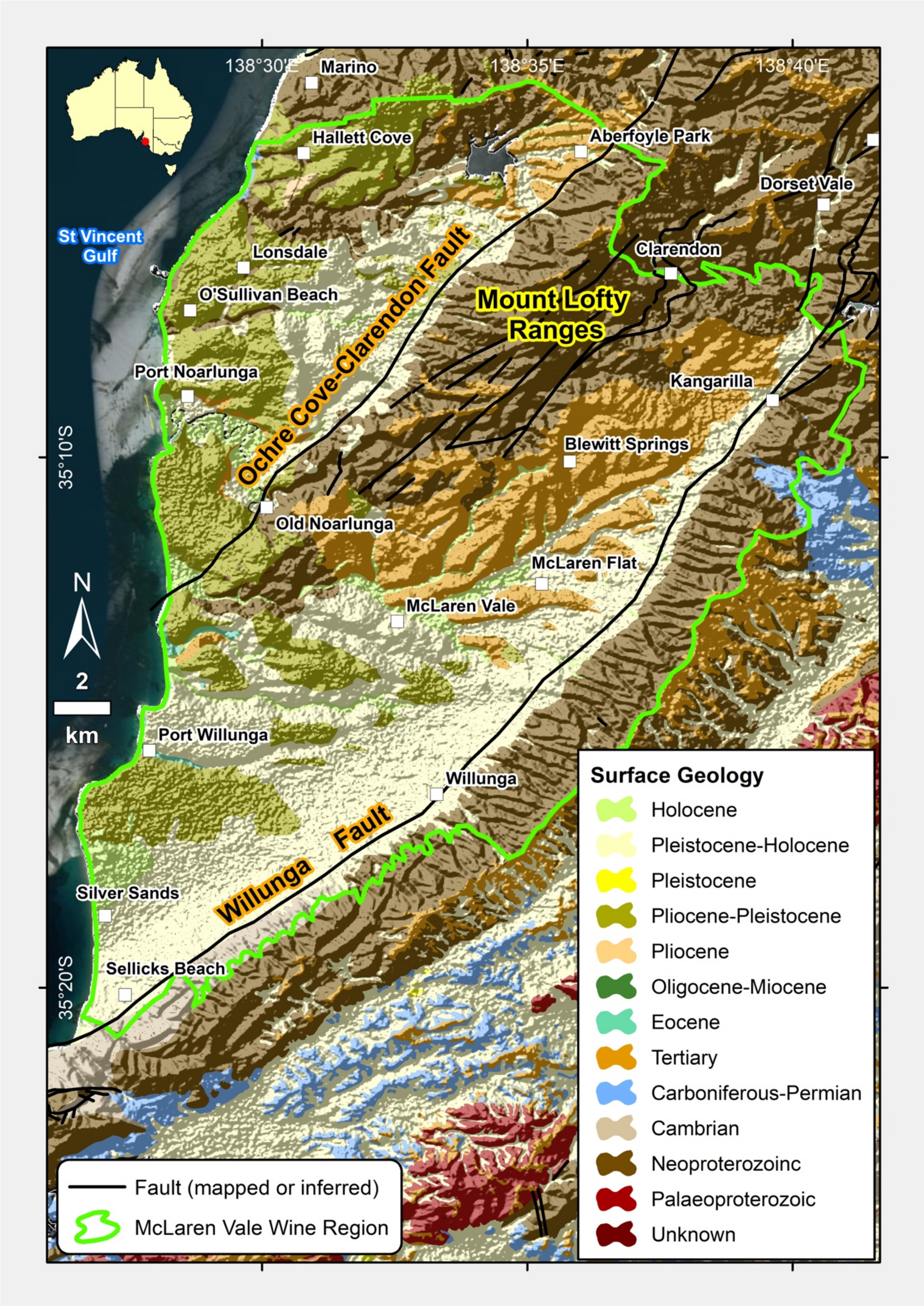

Figure 3. Location and geology of the McLaren wine region in South Australia. 1:100,000 surface geology obtained from the Department of State Development, Resources and Energy of South Australia. Location of faults and boundaries of the McLaren Vale geographic indication derived from the Geology of the McLaren Vale Wine Region map released in 2010.

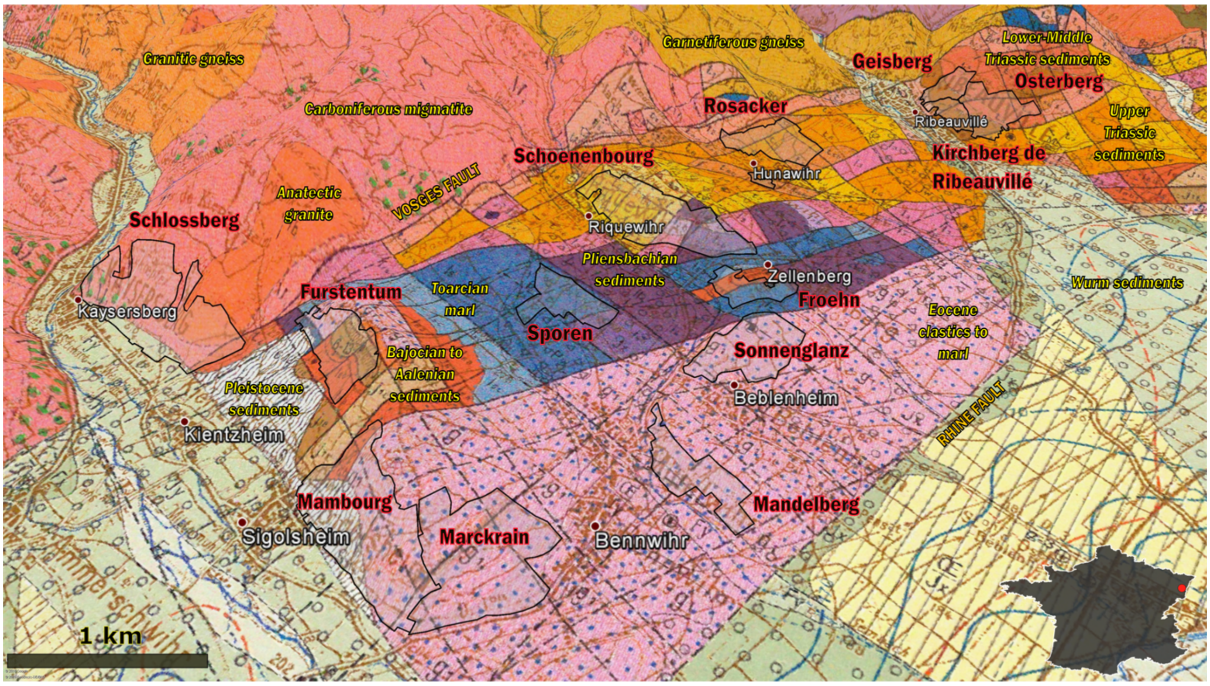

Figure 4. 3D view looking NW showing the location and geology of the Grand Cru plots near the village of Ribeauvillé in Alsace, France. Grand Cru vineyards outlined in black with names in red and black, rock unit names in yellow, and localities in white. 1:50,000 geological map obtained from the French Geological Survey. Geological descriptions derived from the explanatory notes of the Colmar-Artholsheim geological map (BRGM, 1972). Plot boundaries digitised from maps produced by the Alsace Wine Board (www.vinsalsace.com).

Among the 51 top vineyards of Alsace – the 'Grand Crus' – 13 lie within the 10 km of the Ribeauvillé fault field. If price is any indication of quality, 13 of the 25 most expensive Alsatian wines are sourced from vineyards planted on the Ribeauvillé fault network (www.wine-searcher.com, accessed 18 January 2018, see Table 1). The Furstentum Grand Cru places 4 wines in addition to 2 wines made from plots abutting the southern limit of the cru (Altenbourg). All but one of these wines are made from the gewurztraminer grape variety. Interestingly, the Furstentum Grand Cru is also the plot with the most geological variety per hectare in the area (Table 1). Its geology is comprised of 10 different formations within only 0.3 km2: Eocene limestone, Middle Jurassic marl and limestone and Lower Jurassic marl and sandstone. This complexity is explained by the presence of two major sets of structures striking NNE and SSE and defining three compartments in the Furstentum vineyards.

Most of these ranked wines contain some residual sugar associated with either botrytis or late harvest picking. However, the most sought-after dry wine from Alsace is a riesling from Clos Sainte-Hune, vineyard situated in the Rosacker Grand Cru plot (Figure 4), also in the Ribeauvillé fault field. The 1.67 hectares of the Clos are bound by two NE-trending faults, a direction reminiscent of older Permo-Carboniferous structures, and overlie Triassic limestone and dolostone.

Conclusions

This collection of examples drawn from wine regions in Australia, Italy, France and South Africa shows us that geology plays an important role in shaping unique viticultural sites. The nature of the rock formations and their structural relationship first affect the quality of the soil and regional tectonics has an effect on topography and, as a consequence, on vineyard meso-climate.

Table 1. Site and geological characteristics of five Grand Cru plots of the Ribeauvillé fault field in Alsace, France.

Grand Cru	Schlossberg	Furstentum	Mambourg	Schoenenbourg	Rosacker
Area - ha	80	30	62	53	26
Elevation - m	230 – 400	300 – 400	210 – 350	265 – 380	260 – 330
Slope	Steep	Steep	Moderate	Moderate to steep	Low to moderate
Exposition	S – SE	S – SW	S	S – SE	E – SE
Main lithologies	Migmatite, granite	Marl, limestone, sandstone	Marl, conglomerate, sandstone, limestone	Marl, dolostone, limestone, calcareous sandstone	Dolomitic limestone, dolostone
Number of mapped geological formations	3 - Carboniferous metasedimentary migmatites et granites	10 - Eocene to Lower Jurassic sediments	4 - Eocene to Middle Jurassic sediments	12 - Lower Jurassic to Upper Triassic sediments	3 - Middle to Upper Triassic sediments
Main variety	Riesling -76%	Gewurtz.	Gewurtz. - 80%	Riesling	Riesling - 65%
Secondary varieties	Gewurtz. - 13%	Riesling, pinot gris	Pinot gris, riesling	Muscat, pinot gris	Gewurtz.- 23%
Number of wines in top 25 of Alsace	2	4 (+2)	2	1	1 (Clos Sainte-Hune)

Gewurtz. = Gewurtztraminer grape variety. Site characteristics obtained from the Alsace Wine Board website and geological information from BRGM data. Wine price classification (top 25 wines) obtained from the following website: www.wine-searcher.com/regions-alsace, accessed 18 January 2018.

Whether the underlying rocks actually translate into site-specific flavour compounds in the wine is the subject of much research and controversy. The characteristics of a vineyard soil derived from a specific geology conceivably determine some of the flavour precursors in the grape berries. These are later expressed during the winemaking process through yeast metabolism and/or chemical processes in the wine. The crucial step of how soil and geology are contributing to the vine in terms of biochemistry is a complex and poorly understood process.

Geological exploration and the wine industry have more in common than an interest in rock formations. Exploration methods commonly utilised in the mining industry are becoming more and more widespread in viticulture. Drones and multispectral imagery have been contributing to improved vineyard management while ground magnetic surveys (e.g. EM38) help constrain intra-vineyard variability and its impact on grape and, ultimately, wine quality.

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AIG Journal Paper N2018-001
Received 12 Feb 2018
Reviewed 20 Mar 2018
Accepted 1 Jun 2018
Published 6 Jun 2018