What strikes you first when looking at a vineyard? Perhaps the vines themselves. Your eye may be caught by random scatterings of gnarly old bush vines or by the military neatness of the rows, leafy and trimmed in summer but in winter gaunt and skeletal against their trellising. But possibly more striking might be the land itself—the geology, or at least manifestations of it. For the vineyard may be a vast affair, stretching away across a flat plain, or just a tiny huddle of vines clinging to a vertiginous slope, or anywhere in between those two extremes. It all depends on the bedrock geology. The soil may have an eye-catching color or be astonishingly stony, consisting of little more than rock debris. This, too, depends on the geology.
So along with the widely held convictions that vineyard soils have a major influence on wine character and taste, it is no surprise that geology is so often mentioned in accounts of vineyards. (I had better mention at the outset that these days the word ‘geology’ covers Earth processes and materials—so, in vineyards, the ground in which the vines are rooted—and also the scientific study of Earth history.)

The image below is a collage of wine labels—all of which bear something geological—as a graphic reminder of this. The collage includes labels from various vineyards, each with its own unique geological characteristics. (Examples of the very few different geomorphological types of vineyards include terroir, or ‘soil type’, found in the vineyards of Pouilly-Fumé and Sancerre. Bygone peoples frequently allude to the odor of flint or gunflint. Just like the other silicates, however, flint has no taste or smell. Any odor that is perceived when making a spark comes from the mineral fragment of burning iron. The flint remains inert. (Curiously, the word ‘axis’ also appears in wine writings in English, though it is simply the French word for flint.)

I’ve explained that minerals are crystalline because it has important practical repercussions. For example, if we see pieces in a vineyard of what may be fragments of a mineral, how do we go about identifying them—that is, giving them a specific name? The crystalline nature of minerals turns out to be very helpful with this.

Geologists classify minerals on the basis of what elements they contain (hardly surprisingly, seeing that they are combinations of chemical elements). This is straightforward enough in principle (a contrast with the subtle system necessary for rocks). For example, we recognize a group of minerals called oxides, in which some element has combined with oxygen.

Another result of this bonding is that, in almost all minerals, the constituent elements amalgamate not in some higgledy-piggledy fashion but have to organize themselves in a particular, crystalline arrangement. It’s a bit like seeing soldiers on formal parade. This regular pattern, correctly speaking, makes the material crystalline; it is a crystal. In other words, the pieces of mineral in a vineyard are crystalline. (Examples of the very few minerals that are not crystalline include opal, amber, and jet.) We may think of crystals as having the attractive, light-catching facets seen in gem shops and museums, but although this is a manifestation of the crystalline structure of its constituent elements, it is not what defines them as crystals. Consequently, minerals lying in a vineyard may be dull, shapeless chunks, but they are still crystals.

Whether or not a mineral shows smooth crystal faces depends on the circumstances in which the mineral formed. Essentially, to develop attractive external faces, a mineral has to ‘grow’ during its formation into a space and not be constrained by adjacent minerals. In other words, the development of smooth external boundaries in a mineral requires rather special circumstances. The vast majority of minerals will therefore not have such faces—but internally they are still crystals. Therefore, saying that the soils in a particular vineyard are ‘crystalline’ has no geological significance. The ground in all vineyards is composed of crystals of one sort or another. Some of the particles may happen to have smooth faces and catch the sunlight, but this does not make them any more crystalline.

In some kinds of quartz, the crystalline nature is only discernible under a powerful microscope, because the amalgamated crystals are exceptionally minute. This is the case in the variety known as flint, which is particularly well known in the vineyards of Pouilly-Fumé and Sancerre. Bygone peoples learned that striking iron on this hard, strong material was a good way to produce a spark, used at first for lighting fires and much later, utilizing steel, as gunflint. Wine-tasting notes frequently allude to the odor of flint or gunflint. Just like the other silicates, however, flint has no taste or smell. Any odor that is perceived when making a spark comes from the mineral fragment of burning iron. The flint remains inert.
Pure quartz is colorless, like glass or ice. However, just a trace of titanium turns it pink—rose quartz—and a trace of iron gives the beautiful violet of amethyst. Agate, jasper, onyx: All are varieties of quartz (and all have to use shorthand ways. It can be tricky because, unlike many living things, obvious features like size don’t help us, and color can be very misleading. For the other minerals, even tiny amounts of impurity, perhaps lodged in an odd position within the crystal lattice, can have an enormous effect. Thinking back to our prehistoric ancestors, the display would have a very different overall look if one or two of them were in the wrong uniform! Quartz is an excellent example. Pure quartz is simply silicon and oxygen, and it’s colorless, like glass or ice. (Pliny the Elder wrote that quartz was a permanent form of ice.) However, just a trace, for example, of aluminium darkness it to give the semi-precious stone smoky quartz; titanium turns it pink—rose quartz, and a trace of iron gives the beautiful violet of amethyst. Agate, jasper, onyx. All are varieties of quartz (and all occur in certain vineyards and, as a result, find their way into wine names).

A further complication for identification is that certain locations within the crystal lattice of many minerals can be occupied by one element instead of another, leading to a variable composition of the two groups of minerals that chiefly concern us in vineyards: the carbonates, though variable chemistry. This arises in the two groups of minerals that are consistent, even if the chemical composition provides us, in many cases, with practicable shortcuts to identification, for it imparts certain physical properties in a mineral that are consistent, even if the chemical composition is variable and there are ranges of, say, shape and color. Most books on minerals catalog such properties. I will sketch here how two examples work.

First hardness: The mineral gypsum, for instance, is rather soft as minerals go, because in it calcium shares electrons with sulfur and oxygen in a relatively loose way. (Gypsum occurs naturally in some vineyards at Ribera del Duero, Spain, and elsewhere is sometimes added to soils to help reduce acidity.) So, a piece of vineyard mineral that you can dig your fingernail into is a good clue that it might well be gypsum. Quartz, on the other hand, has its silicon and oxygen firmly linked together and arranged in a very efficient three-dimensional lattice. As a result, although it can look superficially like gypsum, quartz is a noticeably hard mineral—even a knife blade won’t scratch it. Together with its chemical stability, this makes the mineral tough, robust, and virtually insoluble. Incidentally, this explains not only why quartz is so common in vineyards, but also why it lacks aroma and flavor (substances have to vaporize for us to smell them or dissolve for us to taste them) and, consequently, is used for wine bottles and glasses.

Second, mineral cleavage. The crystal structure of some minerals has inherent planes of weakness—to the degree that the mineral tends to break along them. In an intact piece, these cleavages may be apparent as hairline traces, such that you can judge how the mineral would fracture. There may be one or more such directions of weakness, or none. Quartz, for the reasons just indicated, has no cleavage at all. It breaks (with difficulty) into shapeless but sharp glassy fragments. Perhaps this is why some wine descriptions refer to a “quartz edge,” as explained above; quartz has no aroma or flavor.

In the crystal lattice of minerals comprising the mica family, there is one direction in which the linking between elements is unusually weak. Hence the micas are distinguishable by their very striking sheet-like shape. It may even be possible to peel the sheets apart. The silvery mica called muscovite (because large, translucent sheets of it were once used as window panes in Moscow) accounts for the flat, shiny particles in the soils of Pouilly-en-Fuisse. France. Looking very similar in most ways but distinctly darker colored, even black, is the other common mica biotite. The ground of the Junco vineyard of Condrieu, France, tends to be pale in color but some patches are noticeably darker because they are rich in biotite. The feldspars (also a complex family of silicate minerals) all have two directions of cleavage, causing them to fragment into block-like chunks, the smooth faces of which catch the light in vineyard areas such as Dão (Portugal) and Temecula (California). With practice, physical properties such as these enable us to identify minerals quickly, but this only comes about because of their crystalline nature.

Rocks and rock fragments

The outermost boundary of the solid Earth is bedrock. Such rock is constantly under the chemical, physical, and biological attacks of weathering, which breaks it down (some may be dissolved) into the fragmentary debris that geologists call sediment. In places such as eucalypt hillysides the bedrock may be visible, protruding through the sediment in outcrops. These days we distinguish between sediment and solid, rigid rock, but it was not always so. The pioneering geologists were keen on determining what they were studying from biological things, so anything made of natural minerals was referred to as “rock.” Thus in this historical usage, river mud, freshly settled volcanic ash, or the sand in a dune would all be termed rock. This sense is still found in some wine writings—in fact, the first three editions of The Oxford Companion to Wine define rock in this way. Modern geology, however, finds it useful to distinguish between loose sediment and rock, the practical difference being, as one wag put it, that kicking a rock hurts your foot.

Geologists classify sediment by the size of the fragments. The largest—boulders—may be enormous, as in mountainous vineyards such as parts of Elqui, in Chile. But while this size is their natural size, some fragments are less difficult, and the silicates, which present formidable problems.

Fortunately, it is the crystalline nature of the minerals that provides us, in many cases, with practicable shortcuts to identification, for it imparts certain physical properties in a mineral that are consistent, even if the chemical composition is variable and there are ranges of, say, shape and color. Most books on minerals catalog such properties. I will sketch here how two examples work.

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All of this has set the scene for turning now to the word that is pivotal to vineyards: soil. Mixed in with the sediments outlined above may be moist, rotted biological material—humus—and this allows the sediment to be called soil. It is, of course, capable of allowing plants to grow in it. So, soil typically consists of a physical framework provided by the geological sediments, spaces between the sediment particles called pores that contain some combination of water, oxygen, and other gases, and a greater or lesser amount of humus. It is the latter and the moisture that make it soil; the moon is covered by porous rock debris, but it has no soil.

If we dig down into a field or garden, normally we see first the humus-rich soil and then underneath increasingly rocky material—subsoil—in which little can grow; and sooner or later we hit bedrock. Only very specialized plants such as lichens can grow directly on bedrock. In fact, in much agriculture the turgor grows in the rocky humus-rich soil at the top, and what lies below is of little relevance. But vineyards are different. The distinction between rock and soil is unusually blurred, because vine roots can penetrate deep into bedrock, and vines can thrive in thin, humus-poor, exceedingly stony soils. Some humus, however, can penetrate deep into bedrock, and vines can thrive in thin, between rock and soil is unusually blurred, because vine roots grow directly on bedrock. In fact, in much agriculture the crops that have a special property (the so-called cation exchange capacity) that allows, in certain circumstances, the release of some of their constituent elements into solution, which now become potential mineral nutrients. Then, if conditions are right, these dissolved elements may be physically transported through films of water between the soil pores toward the vine roots. A series of scientific advances in the late 1800s, however, revealed that it wasn’t really like this at all. Photosynthesis was discovered, a process superficially even more magical. As a result, at least at ten Nobel Prizes later, we know pretty well how plants carry out their growth. It turns out that apart from the water vines are very largely made not from the soil but from the oxygen, hydrogen, and carbon in the air, everything being driven by sunlight. Even so, in order for the photosynthetic and other organic processes utilizing these elements to work, relatively tiny amounts of other elements have to be involved: nutrients. Most of these come from the ground, and consequently they tend to be called mineral nutrients or, often, simply minerals. And here lies the source of much confusion. Although most of these mineral nutrients are derived from geological minerals, they are not the same thing.

The mineral nutrients are chiefly metallic elements, such as magnesium, calcium, iron, and zinc. Although they come from the ground, except by the action of certain specialized fungi (micorrhizae), vines cannot obtain these nutrients directly. To be absorbed by the vine roots, the elements have to be dissolved in the soil water. All this contrasts with the minerals that constitute the vineyard bedrock, stones, and the physical framework of the soil—in the geological sense—which we have seen are almost all rigid compounds, and usually complex and insoluble ones at that. And because, as I emphasized earlier, the elements forming a geological mineral are tightly locked together in a crystal lattice, whole series of processes have to take place before they become detached, dissolved, and transported to the vine roots for possible absorption into the vine system. So, though ultimately linked, there is a major disconnect between these two different kinds of minerals.

Here is a very terse summary of the complex processes that separate the two kinds of minerals. The processes, collectively called weathering, slowly change the nature of the geological minerals and eventually, through a series of intermediate varieties, may lead to the formation of clay minerals. Some of these have a special property (the so-called cation exchange capacity) that allows, in certain circumstances, the release of some of their constituent elements into solution, which now become potential mineral nutrients. Then, if conditions are right, these dissolved elements may be physically transported through films of water between the soil pores toward the vine roots. A series of scientific advances in the late 1800s, however, revealed that it wasn’t really like this at all. Photosynthesis was discovered, a process superficially even more magical. As a result, at least at ten Nobel Prizes later, we know pretty well how plants carry out their growth. It turns out that apart from the water vines are very largely made not from the soil but from the oxygen, hydrogen, and carbon in the air, everything being driven by sunlight. Even so, in order for the photosynthetic and other organic processes utilizing these elements to work, relatively tiny amounts of other elements have to be involved: nutrients. Most of these come from the ground, and consequently they tend to be called mineral nutrients or, often, simply minerals. And here lies the source of much confusion. Although most of these mineral nutrients are derived from geological minerals, they are not the same thing.

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All these processes are aided by the presence of humus and the microbiology it contains. In fact, some amount of humus has to be present in order to help form compounds containing nitrogen, phosphorus, and sulfur, which are essential nutrients but not absorbed in elemental form. The take-up of nitrogen is particularly influential on vine growth and depends largely—oddly seeming as the gas abounds in the air all around the vines—on microorganisms in the soil. And so, if all these kinds of processes are happening smoothly, and the clays and some humus are readily making nutrients available, in at least sufficient quantities, the soil is regarded as being fertile.

**Geological minerals, nutrient minerals, and misunderstandings**

Not only are the processes outlined above intricate, but they vary from place to place and through time. Such things as soil temperature, acidity, humidity, permeability, nitrogen content, microbiology, and so on can all be varying such that any generalizations are fraught. Many populist wine writings, however, give little acknowledgment of these complexities, and this leads to misunderstandings. Here are a few clear illustrations of this.

First, let’s take the mineral nutrient required in the largest quantities by vines: potassium. The chief constituent of the rock granite is the mineral potassium feldspar, so we might expect this particular nutrient to be in plentiful supply in vineyards located on granite—Bia, Stellenbosch, and Temecula, for example. And some wine commentators have it this way. But because of the protracted physical and chemical processes that have to take place, as glimpsed above, in reality only a fraction of the potassium is actually becomes available to the vines. Moreover, the details depend on very localized conditions. The potassium availability differs between soils of different ages, acidity, varying sand, clay, and humus contents, between terraces and the valley floor, and with local variations in rainfall.

Another misunderstanding is the common inference that the vine roots simply soak up like blotting paper whatever happens to be in the soil. It’s as though the vine has to take in whatever the geology throws at it. Vines don’t work like this.

Seventeen or so mineral nutrients are needed for the processes involved in vine growth, and some of these are needed in very different amounts. For every unit of molybdenum, for example, the vine requires about a quarter of a million units of potassium. Moreover, each element is required within a fairly narrow range of optimal values; too little or too much provokes growth problems. (The extent to which variations within the optimal range mechanisms is at present not known.) As a result, vines have evolved highly sophisticated mechanisms of selecting and balancing the relative amounts of nutrients they require. Some of these needs are met but not exceeded. To this extent, vine nutrition isn’t dependent on the nature of the vineyard geology; provided it can yield sufficient nutrients, in general most soils can yield sufficient nutrients, unless they are being overcultivated.

That said, there is some passive uptake of soil water and its content, and the vine’s selectivity processes are fallible. For example, we have already glimpsed the calcium and magnesium complications within geological minerals, and it is the same when these two elements are acting as nutrients. A vine’s filters may be unable to distinguish between the two, and the more plentiful one becomes absorbed to the detriment of the other. Hence, vine diseases such as the leaf-browning we sometimes see in parts of vineyards don’t necessarily mean that a particular nutrient mineral is unavailable in the soil. Some other nutrient, perhaps more abundant or more easily absorbed, may be lodging the vine. The effect differs between different cultivars and varieties, especially different rootstocks, which vary markedly in the way they take up mineral nutrients. This is why growers are advised to assess nutrition by analyzing parts of the plant itself, as they may in order to see what the vine’s filters are taking up rather than what the geology contains. This is why a grower walks his vineyard. The key to monitoring its health lies in watching the vines, not in believing the geology.

Another point often overlooked is that although certain amounts of nutrients are essential for growth, the vine does not care, so to speak, where they came from. Whether a mineral nutrient originated in a particular rock or this or that geological mineral is irrelevant to the growth processes. A vine’s hormonal system may signal to its roots the need for some nutrient—magnesium, say—and provided it is available in the soil water, then magnesium will be allowed to negotiate the roots’ regulatory screens and gradients to be absorbed into the vine system. But whether the element was originally in a chunk of
Science has in no way diluted the romance of vineyards and wines—quite the contrary. If we are brought to recognize more fully the sheer complexity of the natural processes involved, it increases our admiration, it adds to the marvel.

Above: Volcanic areas are known to contain sulfur naturally, though much sulfur in vineyards is added artificially to increase acidity.