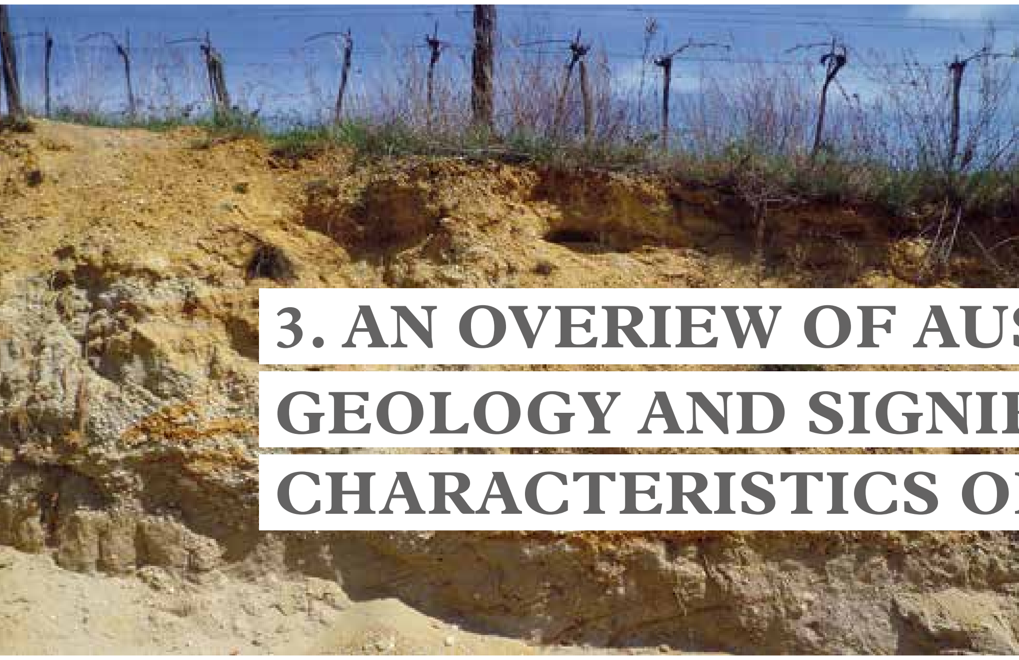


3. AN OVERIEW OF AUSTRIA'S GEOLOGY AND SIGNIFICANT CHARACTERISTICS OF ITS ROCK

Gravels from the Upper Danube in Radlbrunn (Weinviertel), photo: M. Heinrich 2012

LANDSCAPE AND ROCKS

The scenic landscape of Austria has been significantly shaped by the main geological units: the highlands of the Waldviertel and Mühlviertel regions form part of the Bohemian Massif in the north, followed by the undulating hilly Alpine Foreland with great valleys and basins in the east, and finally the mountainous Alps, which extend for over 500 km lengthwise across the country. The Eastern Alps are part of a large mountain arc that extends from the Riviera to Vienna and form, seen from a geological perspective, a crumpled zone where the Adriatic and the Eurasian Plates encounter each other. The continuation of the Alps occurs underneath the basins in the east of the country, covered by sediments of up to 5000 m in thickness, and reemerges in the Carpathian and Dinaride mountain ranges. The large-scale structures are the result of plate-tectonic developments, which have brought about formation of rocks that are now hundreds of millions of years old, alteration of the distribution of land and water, displacement and breakup of continents, separation and isolation of seas as well as the uplift and subsequent erosion of mountains.

However, rocks and the course of tectonic boundaries also have a direct impact on the landscape on the smaller scale. Soft, easily-weathered rock tends to give rise to gentle landforms while rugged mountain shapes and steep cliffs are usually related to hard and brittle rock types. Valleys often follow the trend of tectonic faults. Due to rapid erosion in areas with soft bedrock canyons and almost vertical undercut, slopes can form along rivers. Conversely, where there is underlying hard bedrock under suitable climatic conditions and with small height differences, undulating and gently-rolling landscapes may be formed.The great climatic fluctuations of the Quaternary Period proved essential for landscape development in the Alps in more recent geologic times, with the effects of at least four glaciations or cold phases of the so-called Ice Age being present. The abrading force of the great glaciers and frost shattering caused large quantities of rock to be eroded. Due to alternating erosion and deposition by the glacial meltwaters, gravel terraces formed and as a result of the drift of rock dust from the barren mountains, loess was formed in the foreland areas.

In addition to composition of the rocks, tectonic boundaries, uplift and subsidence of the land surface and climate development, factors such as vegetation and human interventions also contribute to the character of the landscape.

Since the major rock units basically travers Austria in a lengthwise fashion, while the winegrowing regions trace an arc in the east of the country, these consequently include manifestations of almost all the main geological units. This is why our wine landscapes are so varied and interesting!

Rocks can have very different cohesion properties, thus the first rough division is accordingly made between consolidated and unconsolidated rocks. About seventy per cent of our domestic vineyards are located on unconsolidated bedrock, with about thirty per cent positioned upon soils that have been derived from solid bedrock.

Types of consolidated rock relevant to this case belong to the following major geologic units in Austria:

- The Moldanubian and Moravian Superunits occurring in the area of the Bohemian Massif consist of crystalline rocks of Proterozoic and Palaeozoic age
- The Helvetic Superunit and klippes of the Waschberg Zone, formed from rock deposits (sedimentary rocks) of Mesozoic and early Cenozoic age
- The Penninic Superunit composed of rocks derived from an ocean that existed in Mesozoic and early Cenozoic time. On the northern edge of the Eastern Alps lies the Penninic Flysch Zone. Similar rocks are found in altered (metamorphosed) form in the region of the Central Eastern Alps where they are exposed in so-called tectonic windows below the Austroalpine Superunit

- The Austroalpine Superunit, formed from rock deposits of late Palaeozoic, Mesozoic and early Cenozoic age in the Northern Calcareous Alps and the Gosau Group, and consists of altered rocks (metamorphic rocks) and rock deposits (sedimentary rocks) of Proterozoic, Palaeozoic and Mesozoic age in the Central Eastern Alps

The unconsolidated rocks belong to the following geological units:

- Molasse Zone in the Alpine Foreland, formed from rock deposits of early and late Cenozoic age (Palaeogene and Neogene) up until about 7 million years ago
- Inner Alpine basins such as the Vienna Basin, Styrian Basin and the Pannonian Basin, composed of rock deposits of the Cenozoic (Neogene) up until about 2.6 million years ago
- Deposits of the most recent geological period, the Quaternary, which are concentrated in the Molasse Zone and in the basins, but also overlap onto areas of consolidated rocks

Within the unconsolidated rock domains, there are also occurrences of consolidated rocks:

- Consolidated sands, gravels and rock debris forming sandstones and conglomerate or breccia
- Leitha limestone
- Volcanic rocks within the Styrian Basin

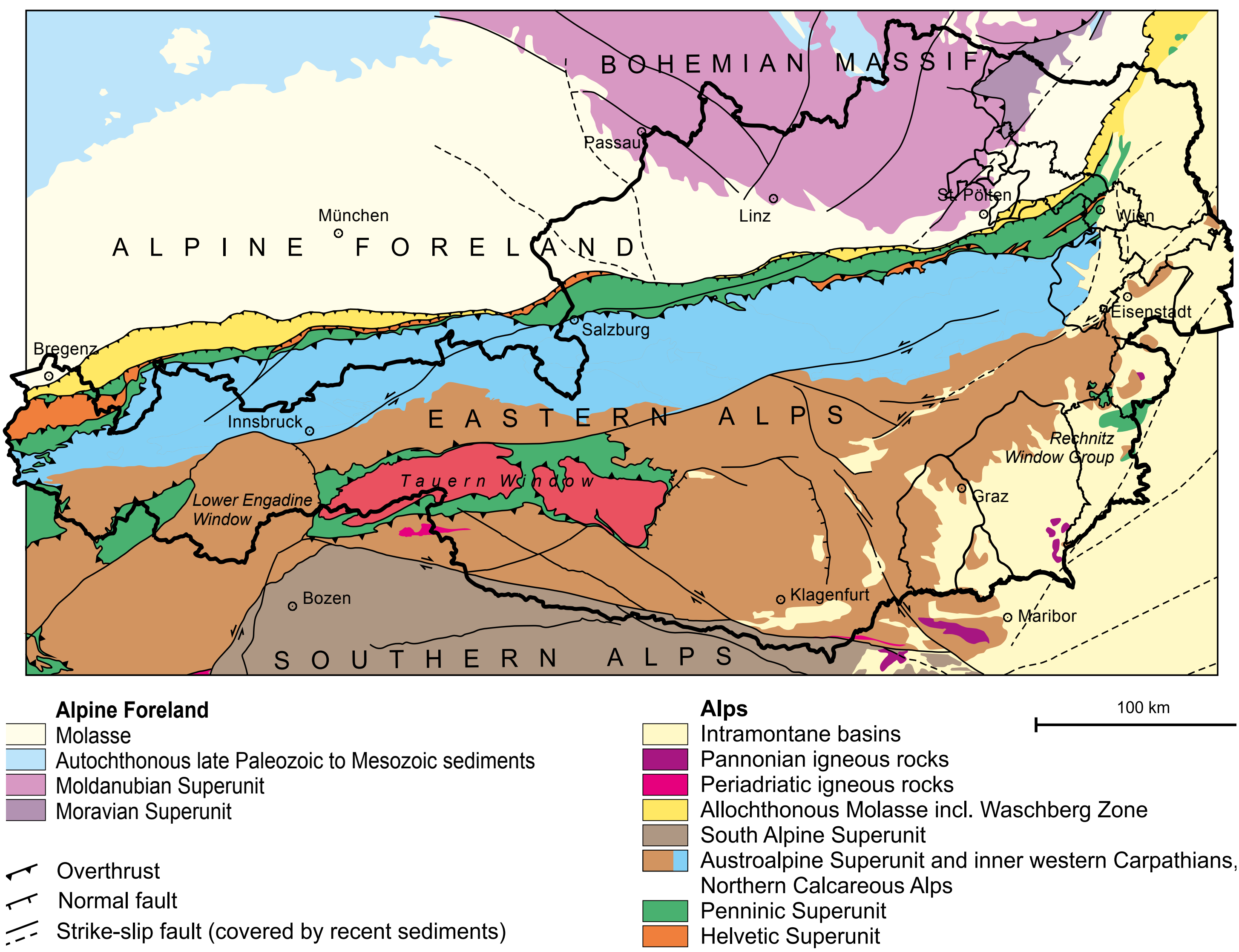
The limits of the large units of time are:

Proterozoic: older than 541 million years

Palaeozoic: 541 - 253 million years

Mesozoic: 253 - 66 million years

Cenozoic: 66 million years – present time, the Neogene / Quaternary boundary is placed at 2.6 million years ago, the Pleistocene and Holocene boundary is placed at 10,000 years before the present.



Silts and sands from Lake Pannon in Gols (Neusiedlersee), photo: M. Heinrich 2006

The main geological units of the Austrian winegrowing regions

The Moldanubian and Moravian Superunits are deep portions of an ancient mountain range, which extended from central Europe over the Iberian Peninsula to the Appalachian Mountains in North America. The southern end of these two units forms the Waldviertel region. The mountain range developed during the so-called Variscan Orogeny before 360 to 300 million years ago on the southern margin of 'Old Europe'. The formerly high mountains were mostly eroded, flooded by seas and parts have only been uplifted again during Cenozoic time to form a low mountain range. The present-day, undulating highland landscape has been deeply incised by the Danube and its tributaries from the north. The range of rocks is varied and colourful and the prevailing rock types are granite, gneiss (paragneiss – orthogneiss) metamorphosing from former sediments or igneous rocks, amphibolites attributable to volcanic activity, granulites, quartzites and marbles.

Helvetic Superunit and klippes of the Waschberg Zone: the rocks of the Helvetic Superunit are marine deposits and in the Vienna area occur as wedges within the flysch rocks in the form of red, green and grey, partly marly clays with thin layers of quartz sandstone. Like the rocks in the Bohemian Massif and the light-coloured, pure limestone klippes of the Weinviertel Waschberg Zone they belong to the depositional environment of 'Old Europe'. However, in contrast to the Moldanubian and Moravian Superunits, they were included during the Cenozoic within the Alps.

The rocks of the Penninic Superunit are remnants of a past ocean, the so-called Penninic Ocean. The flysch rocks on the northern margin of the Calcareous Alps in Lower Austria and Vienna are composed of a characteristic, often repeating sequence of sandstones, silt- and claystone or marl. They formed from mudslides that flowed from the shelf edge into the deep sea. In southern Burgenland rocks associated to the Penninic Superunit are exposed in a tectonic window: these include green schist that developed from the ocean floor basalts, serpentinite, former mantle rock, and altered ocean basin sediments such as calcareous schists, phyllites and quartzites.
The rocks of the Austroalpine Superunit were originally located on the northern edge of Africa, and later formed the northern margin of the Adriatic Plate. They form the Northern Calcareous Alps (Lower Austria and Vienna) and the Central Eastern Alps (Lower Austria, Burgenland, Styria). The sediments and volcanic rocks from which the oldest rocks of this unit are derived, are more than 540 million years old. These include paragneiss, mica schist and amphibolites. Later, granite was intruded, being altered to so-called orthogneisses. In Palaeozoic time there followed deposition of sandy-clay sediments with intercalated basalt lavas and tuffs, calcareous reefs, sands, gravels, and salt and gypsum deposits. Many of these rocks later underwent deformation and alteration to varying degrees and occur today as phyllites, mica schists, marbles, quartzites and amphibolites. Some were penetrated by molten rock from the Earth's interior which consolidated to form granite or pegmatite. The youngest and topmost sedimentary rocks of this unit are of Mesozoic vintage and were deposited in a shelf, which was located on the edge of the Tethys Ocean, and later lay between the Tethys and Penninic Oceans. The rock sequence begins with red shales and sandstones followed by bedded limestones, massive reef limestones, bedded dolomite, intercalations of sandstones and clayey sediments and, in turn, carbonate rocks which originated in reefs and lagoons. There are also siliceous limestones and radiolarites that formed in deeper marine areas. Starting with the tectonic movements at the end of the Mesozoic the rocks of the Gosau Group were deposited, consisting of sandstones, marls, conglomerates and marly limestones.

Molasse Zone and Inner Alpine Basins: the Molasse Zone of the Alpine Foreland in Lower Austria includes gravels, sands and silty-clay sediments, which formed in a basin in front of the approaching nappes of the Alps. The majority of the sediments developed as the basin was filled by the so-called Paratethys Sea during Neogene time. They were deposited in deep and shallow waters, on the coasts and in deltas. After the sea had retreated, lakes and rivers were formed. The deposited material came largely from the uplifting, primarily calcareous rocks of the Alps in the south and to a lesser extent from the dominantly silicate rocks of the Bohemian Massif. The history of the Inner Alpine Basins in eastern Austria (Weinviertel region, Vienna, Burgenland, Styria) begins somewhat later. They formed due to a plate-tectonic related, easterly directed extension. However, a similar development of marine (Paratethys) to freshwater deposits is found. Under brackish and freshwater conditions (Lake Pannon) these basins finally became silted up and alluvial deposition became dominant. The sediments include rock debris, gravels, sands, silts and clays with varying amounts of carbonate content, which were supplied from the adjacent uplifting mountains. In quiet shallow marine areas, limestone developed, such as the Leitha limestone, composed of skeletal fragments of lime-precipitating red algae. Where rivers flowed into the sea, we now find gravels and conglomerates, and in the basins silts, clays and clay marls also referred to locally as schlier. The most recent marine sediments are about 12 million years old. In the Styrian Basin, deposition was accompanied by an intense volcanic activity about 15 million years ago, remnants of which can be found near Bad Gleichenberg and Weitendorf.

The geological development of the Quaternary, the most recent geological time period, started about 2.6 million years ago and is still ongoing today. It is of great importance for all the wine regions of Austria. The essential characteristic of this geological period is the repeated alternation of cold phases (glacials) and warm intervals (interglacials): the last Ice Age ended in the Pleistocene about 10,000 years ago. These climate fluctuations are responsible for the shaping of the landscape with its valleys, terraces, hills and mountains, as we know them today, and also for the types of the most recent deposits. In Styria, about 2 million years ago, there was a second volcanic phase, to which the rocks of the areas of Klöch, Kapfenstein and Riegersburg are attributed.

The wine regions of Austria were not glaciated during the cold phases but were located in the vicinity of the glaciers, in the so-called periglacial areas. The latter were marked by intense freezing, frost and reduced vegetation cover. The glaciers planed large amounts of rock from the mountain ranges, which were transported as boulders by the meltwaters into the foreland areas and deposited there under decreasing rates of drag force and transport capacity. They form the terrace landforms into which the rivers cut when subject to renewed swelling, thus giving rise to a staircase of old valley floors with younger terraces occurring in a downward direction, ending with the present-day flood plain. Loess also developed in the same time as the terrace gravels during the cold phases of the Quaternary. It consists of rock dust blown by the wind from the vegetation-free, dry plains in front of the glaciers which was redeposited in the foreland areas, in particular on the east- and southeast-facing slopes. Loess shows a characteristic flour-like consistency and is yellow in colour. It is always calcareous, but with a varying content ranging from magnesium-free calcite to magnesium-bearing dolomite. Typical features also include its porosity and high degree of stability in the dry state: for example, the walls of narrow gorges remain standing while the non-compacted floor subjected to severe wetting is eroded deeper and deeper. Not all loess is preserved in the classic form: the ground became frozen at depth during the cold periods, thus only the slightest dip in slope was required to cause superficially thawed, water-saturated material to slide. Consequently, due to its altered structure, weathering and multiple freeze/thaw cycles caused further changes. Through these processes loam was formed, which is decalcified loess with increased clay content. In the terrain where deposits are exposed, both horizontal and vertical gradation of loess and loam can be seen: such occurrences make it extremely difficult to delimit these areas on geological maps.

Extremely 'young' geological processes such as weathering as well as extensive erosion and reaccumulation of deposits in linear streams and on slopes are of great importance for winegrowing. Products of these processes include loosening and disintegration of consolidated rocks, loamification of clay and micarich rocks, talus and alluvium, alluvial fans, muds, slope wash and colluvium as well as overbank loam and ultimately the soil-formation above all parent-rocks; the soil that supports and anchors the vines and serves as a water and nutrient reservoir.

Soil is a mixture of weathered rock and organic matter, in addition to its content of water and air. The formation of a soil usually starts at the surface of the rock, which can be either unconsolidated or consolidated, and progressively increases in depth over time. Soil formation and its further development takes place over long periods of time under the influence of various factors such as climate, groundwater, surface relief, vegetation, soil organisms and human use.

The three major rock groups

There are three superordinate groups of rock differentiated by geology:

- solidification rocks or igneous rocks occur as intrusive rocks (plutonic rocks) or as extrusive rocks (volcanic rocks)
- deposits or sedimentary rocks
- alteration or metamorphic rocks

Intrusive rocks and metamorphic rocks are also grouped under the term crystalline rocks. Crystalline rocks are commonly summarised within the wine community under the term 'Urgestein(= primordial rock). Urgestein is a term that alludes to the great age of rocks. The term is not precise from a geological point of view and does not do justice to the diversity of the rocks with reference to their distinct properties – such as chemistry, mineral composition and texture – that are relevant to viticulture.

Igneous rocks are rocks that have solidified from a melt. Solidification of intrusive rocks occurs within the Earth while that of the extrusive rocks takes place on the Earth's surface, whether on land or in the sea. The chemical and mineralogical composition of each may be very different: intrusive rocks are rather coarse-grained, for instance granite; extrusive rocks are rather finely grained, rarely glassy, one example being basalt.

Loess in Oberdürnbach (Weinviertel) © Thomas Hofmann

Volcanic tuffs in Kapfenstein (Vulkanland Steiermark), photo: M. Heinrich 2014

Crystalline gneiss with amphibolite blocks from Achleiten (Wachau); photo: M. Heinrich 2008

Conglomerate from the Zöbinger-Formation with characteristic red feldspars and clasts at Heiligenstein (Kamptal), photo: T. Untersweg 2006

Sedimentary rocks occur on the Earth's surface as erosion products of other rocks (clastic sediments) or as precipitates from water or by organisms (chemical and biogenic sediments). Clastic sediments are differentiated according to grain size in boulders, stones, coarse rock debris and gravel, sand, silt and clay. The process of consolidation is called diagenesis: then one refers to breccia, conglomerate, sandstone, siltstone and mudstone. Limestones are formed from the frameworks and skeletons of organisms. Upon consolidation, limetsone can be converted to dolomite from input of magnesium.

Metamorphic rocks are formed when rocks in a solid state are subjected to variations in temperature and pressure conditions. This process is usually associated with some form of deformation, such as foliation or alteration in texture, related to changes in the water content of the rocks. The latter may result in alteration or formation of minerals.
Granite is altered to orthogneiss, limestone to marble, quartz sandstone to quartzite. Basalt may be altered to greenschist, amphibolite and, at very high pressure eclogite. Clayey and sandy sediments with increasing degrees of metamorphism are altered to slate, phyllite, mica schist and paragneiss and, at temperatures above 700°C, socalled migmatites.

Rocks are part of a cycle that repeats itself over and over: a topographical relief may be formed due to processes such as orogenies, volcanism or basin subsidence. Then rock material is eroded from the relief. This is deposited elsewhere as sediment. In the course of a subsequent orogeny sediments and their basement subside, become metamorphosed and undergo partial melting. As a result of uplifting processes a relief is again formed and the cycle repeats itself.

Important rock properties for winegrowing

Type and composition, age, formation, structure and bedding allow geologists to draw far-reaching conclusions not only regarding the geological development, but also in relation to the significance of rocks for mankind, economic and cultural development and sustainable public services. In addition to the distinction between consolidated and unconsolidated rocks from among the variety of parameters used to determine rock properties the following are the most important for viticulture:

- structure or texture
- mineralogical and chemical composition

In describing the structure of a rock, specification is given of whether a consolidated rock is coarse-grained or fine-grained, whether it is massively, coarsely or finely bedded, layered, foliated, jointed, fractured, weathered or dehydrated. In unconsolidated rocks it is important to pay attention to the grain size distribution and the particle shape, the degree of rounding and possible compaction. A very important factor to consider is the content of pore space and of the smallest rock particles (< 0.002 mm) with a large inner surface, the so-called clay minerals.

The individual grain size fractions are:

boulders: > 20 cm	sand: 0.063-2 mm
stones (pebbles): > 63 mm	silt: 0.002 to 0.063 mm
gravel (angular: grit): 2-63 mm	clay: < 0.002 mm

In nature, various grain-size fractions are usually mixed together, such as in clayish silt or sandy gravel.

Structure has an impact on the weathering behaviour of the rocks, the heating and root penetration capacity of the soil, the air, temperature and water balance, and through the content of clay minerals, on the transfer of nutrients.

COMPOSITION OF THE ROCKS

Minerals are the building blocks of rocks. Most rocks are formed of several minerals such as granite with feldspar, quartz and mica. Few rocks consist largely of only one mineral, such as limestone with calcite or quartzite with quartz.

Minerals have an ordered internal structure and a specific chemical composition, and they themselves in turn consist of one or more elements or compounds.

The main rock-forming minerals are:

a) silicates (their main components are silicon, aluminium and oxygen) such as feldspars (plagioclase and alkali feldspar), amphibole and pyroxene, quartz, mica, clay minerals, garnet and

b) carbonates such as calcite (calcium carbonate) and dolomite (calcium magnesium carbonate).

Other groups form the phosphates, oxides, sulphides and sulphates.

Common minerals in the three major rock groups are:

Igneous rocks: quartz, feldspar, mica, pyroxene, amphibole, olivine

Sedimentary rocks: quartz, clay minerals, feldspar, calcite, dolomite

Metamorphic rocks: quartz, feldspar, mica, garnet, staurolite, kyanite

The chemical and mineralogical composition of a rock determines the natural supply of nutrients and thus impacts on the choice of materials and varieties. The amount and type of clay minerals, having different properties with respect to water uptake and ion exchange capacity, has a strong influence on soil structure and workability, the behaviour of the soil water, on the binding and release of nutrients such as potassium and magnesium, and also on the susceptibility to erosion.

Further Reading

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Geological Survey of Austria

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