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Soils of the Viticultural Regions of Hesse

1. The Viticultural Survey of Hesse

Since the extensive adoption of grafting in viticulture, grape yield of the European scions is essentially dependant on the tolerance of the Phylloxera-resistant American rootstock to soil conditions. As a consequence, the state authorities initiated an extensive and systematic soil survey of the viticultual regions of Hesse in 1947, as part of an endeavor to promote viticulture. The objective of the survey was to identify soil conditions in order to facilitate optimal rootstock selection.

This entailed drilling 40 – 50 two-meter deep sample holes per hectare in order to understand and identify small-scale soil variability. About 10,000 ha were surveyed in this manner, an area far greater than the permitted area for growing wine (area under cultivation + area with permits for growing wine). The fieldwork was augmented by laboratory measurements.

At the time of the preliminary conclusion of the project in 1958, the results were presented in 183 soil maps containing approx. 1700 soil units (scale 1: 2.000). Each community has been presented with copies and the maps can be viewed at the State Office for Viticulture in Eltville (see Pinkow 1948 and Zakosek et al. 1979). The survey data is currently being digitized and integrated into the Soil Information System (http://weinbaustandort.hessen.de/viewer.htm).

This formed the basis for the joint effort publication of the 1: 5.000 scale Viticultural Site Maps of the Rheingau by the Hessian Agency for Environment and Geology, the meteorological station Geisenheim (National Meteorological Service Germany) and the Geisenheim Research Center. This set of maps includes the results of the soil survey as well as those of the agricultural meteorological survey and the results of the soil–rootstock adaptation program. This comprehensive information forms the basis for deriving recommendations for cultivars and cultivation measures.To date this publication includes 16 maps covering most of the Rheingau and Maingau regions and is available from the Hessian Agency for Environment and Geology.

Continued efforts to complete the Viticultural Survey of Hesse (Zakosek et al. 1967) resulted in a revised edition of the 1 : 50.000 scale soil map of the viticultural regions in Hesse including the Gross-Umstadt region which had been omitted previously. The project was completed in 1995 by the Hessian Agency for Environment and Geology.

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2. The ecological soil units of the viticultural site map

Vineyard soils are generally placed within the group of terrestric anthropogenic soils or anthrosols. These soils have been created and intensively modified by human intervention. In the German soil classification system, all vineyard soils are classed as “Rigosol”. The name reflects a particular management practice common to all vineyards. Nearly all vineyard soils have been deep-cultivated before planting.

Fig. 1. Typical "Rigosol" with stony backfilled soil material to 1m over Tertiary marine sands (Greifenberg).

Before the extensive adoption of Phylloxera-resistant rootstocks, vineyards were usually restocked and therefore deep-cultivated every 30 to 80 years. In some rare cases, this cycle lasted more than 100 years. Since then (from 1850 to the present day) it has become necessary to reduce the lifecycle of vineyards to 20 to 40 years. Bearing in mind that some vineyards have been under cultivation since Carolingian times it is evident that these vineyards have been subjected to at least 15 to 20 such management cycles. Until about 50 to 60 years ago, vineyard soils were manually cultivated to depth of up to 100 cm using hand tools, a process known in Germany as “rigolen”. Today, special deep-ploughs are used to cultivate the soil to a depth between 40 and 80 cm. Repeated deep-cultivation has destroyed the natural stratification of the soil and thoroughly mixed the soil materials (Fig. 1). Since most vineyards are located on shallow soils, unweathered parent material was incorporated into the R-horizon (R for Rigolen, the deep-cultivated horizon). Before the widespread use of artificial fertilizers, various materials such as slate, marl and loess were incorporated into the R-horizon to improve soil conditions. Many vineyard soils have therefore been changed by repeated additions of large quantities of alien materials. This process continues even today as soil and rock material as well as large volumes of excavated earth, coal ash, pomace, mud, compost etc. is brought into the vineyards. In view of this long-term recurrent modification of the soil by deep-cultivation and addition of alien material, these soils are best described as terric anthrosols.

The typical vineyard terraces of the Central Rhine Valley were originally designed to facilitate cultivation and reduce soil erosion. However, their construction required the movement of large volumes of earth especially in very steep slopes where the dry walls were firmly anchored to the underlying bedrock. This construction necessitated the removal of the loose material cover, which was then used to fill the vineyard terrace. As a result, many soils of the steep terraced slopes almost completely consist of rock material excavated and moved during their construction.

The outcome of these management practices is that the natural original soil has been completely lost or eroded, in many vineyards. However, in order to improve the destitute soils, the bedrock has been covered with a thick layer of alien materials from 50 cm to several meters. Figure 1 shows a typical soil supplemented with mostly alien materials. Very often, as in this case, stony material was incorporated to reduce erosion losses. In accordance with § 12 of the Federal Soil Protection Regulations (see Hessisches Landesamt für Umwelt und Geologie 2003), the current recommendations for soil amelioration in new vineyards aim to preserve the layered character by using local materials.

These intensely altered soils, created by excavation and filling, cover a significant area of the wine growing regions. The traditional vineyard soils (Rigosol - terric anthrosol), which are formed by deep-cultivation, are still found in numerous locations (Fig. 2). This method destroys both - the original soil horizons and the structure by thoroughly mixing the soil constituents to cultivation depth. This practice preserves the mineral matrix, which determines the unique properties and characteristics of each Rigosol. Depending on the thickness of the soil cover, the associated soil may be preserved beneath the R-horizon. In some cases the associated soil can be deduced from the cultivation horizon.

Anthrosols are classified according to the nature of the modified horizon (1st qualifier) and that of the associated underlying soil (2nd qualifier). For example, a luvic terric anthrosol is a terric anthrosol developed from a luvisol. The large number of possible permutations between parent material and the modified soil class results in a vast number of soil units depicted in soil maps.

In order to facilitate the use of these maps for site evaluation purposes, numerous soil units were combined and assigned to seven soil groups according to specific viticultural-ecological criteria (Table 1). The main criteria used to distinguish the groups are soil pH and water budget, since grapes grow best in weak acid to neutral soils with a balanced water budget.

Fig. 2. Typical Rigosol with deep-ploughed modified topsoil to a depth of 55 cm over Tertiary marine sediments (Greifenberg).

Tab. 1. The seven soil groups of the wine-growing regions of Hesse.

Soil group I	predominantly shallow, very stony, dry, usually non-calcareous soils
Soil group II	moderate to deep, stony, loam-containing, dry to moist, usually non-calcareous soils
Soil group III	deep, less coarse, loam-containing, moist, base enriched, usually non-calcareous soils
Soil group IV	clay-rich, occasionally stony, often waterlogged, usually non-calcareous soils
Soil group V	deep, rarely stony, silty, rarely silty sandy, dry to mostly moist, mostly calcareous soils a) deep sandy to sandy silty , mostly calcareous soils
Soil group VI	deep, frequently stony, clay containing, moist to wet, mostly calcareous soils
Soil group VII	clay-rich, less stony, often waterlogged, mostly calcareous soils

The seven soil groups are identified as follows:

Soil group I only covers about 3.5 % of the wine-growing regions in Hesse. The soils of this group are limited to exposed reliefs such as the upper slopes and summits covered by stony solifluction deposits with very little loess over carbonate-free bedrocks such as quartzite, slate, quartzitic-arenites, phyllites and gneiss (Rheingau) as well as sandstone, grano-diorites and diorites (Bergstrasse and Gross-Umstadt). The corresponding unconsolidated parent materials include the pleistocene gravels and sands of the Rhine river terraces and the Tertiary marine sands (Rheingau and Maingau). The terric anthrosols are usually developed on shallow cambisols, as well as very shallow, nutrient deficient and acidic regosols. These coarse soils are very well aerated and highly permeable, but with little water storage capacity. Their water capacity is so low that even in wet years the vines cannot be supplied with sufficient amounts of water. Satisfactory yields can only be achieved by irrigating these soils.

Soil group II includes those soils found on thick solifluction deposits, which consist of transported rock debris as well as weathered material from the underlying bedrock. In most instances, these solifluction deposits also contain loess. These soils are found only on steep slopes or at higher elevations. Soil group II also includes soils developed on sandy-gravelly substrates with an appreciable loess content. The associated soils include loess-containing Cambisols and degraded Luvisols. These soils are usually nutrient deficient and acid. Growing conditions at these locations can be improved by soil amelioration measures such as the addition of fine earth or irrigation.

Soil group III includes soils with very positive growing conditions. A well-balanced water budget is mostly combined with a high plant available water capacity with little danger of drought or saturation. These moderately acidic, deep terric anthrosols are very fertile and provide optimum growing conditions for vine roots.

Group III soils are usually associated with luvisols developed on loess and sandy loess parent materials usually found on peneplanation areas and stretched or slightly concave middle slopes.

Soil group IV contains soils suffering from intermittent waterlogging, often due to a compacted subsoil. During wet periods, the volume of percolating water exceeds subsoil permeability, causing water to accumulate in the coarse pores of the topsoil, thus severely limiting aeration. This causes a temporary lack of oxygen, lowering of the soil-pH and a depletion of bases. Since these soils are usually waterlogged in the winter half-year, they are slow to warm in spring. The compacted subsoil prevents roots from penetrating deep into the profile, so that the vine is also subjected to water stress during the summer droughts.

The intensity of these conditions and characteristics varies considerably between locations and may also be present as a relic. Group IV soils are found on the plateaus and slightly inclined upper slopes of the higher parts of the Rheingau where a layer of clay-containing rock debris is covered by a thin layer of lighter material.

Soil group V is the most important soil group covering about 34 % of the viticultural region. These soils are usually associated with calcaric regosols developed on loess, which are in themselves eroded eutric luvisols. These soils are usually found along slopes where the silty material is subject to a high risk of erosion. Eroded loess soils are alkaline and tend to dry out during the summer droughts when located in exposed positions. On the positive side, such soils are well aerated and deep, providing vine roots with plenty of space to grow.

Soil Group Va is a new sub-group, introduced to cover calcic regosols formed on calcareous aeolian sands, for example loess sands. These pleistocene sediments were blown out of the gravel beds of the Rhine and deposited along the lower foothills of the Bergstrasse between the Rhine Valley plains and the Odenwald and the Maingau, north of the River Main.

Soil group VI embraces the floodplain soils of the river and stream valleys. The parent materials are usually fertile, calcareous, alluvial fine sediments normally with a low humus content. The prevalent soils are semiterrestric soils such as fluvisols and gleysols with fluctuating groundwater levels. In some cases, these soils may be temporarily flooded. The roots of the vine will only grow in the space above the groundwater level where the soil is aerated for longer periods. The groundwater level should be at east 80 cm beneath the soil surface to provide sufficient rooting depth.

Soil group VII contains anthrosols associated with calcaric regosols developed on tertiary clay and silty marls of the Mainz Basin. These soils are often found in the upper Rheingau and in the Maingau along SW-facing steep slopes where the layers have been exposed by gullies. The slopes are so steep that these layers were not subsequently covered by thick beds of loess. Group VII soils have a high water capacity. However, a large part of the stored water is unavailable to plants. Their suitability for growing wine is also restricted by a low transmissivity and inadequate aeration. Considerable swelling and shrinking severely aggravates cultivation measures and restricts root penetration.

3. The soils of the viticultural regions

The formation of soils, their attributes and properties is partly determined by the topography and geology of the location. Both factors vary considerably between the viticultural regions of Hesse, namely Middle Rhine, Rheingau, Maingau, Bergstrasse and Dieburg Basin. This variability has led to the development of a characteristic regional soil distribution and is reflected in the wide range of vineyard soil types. The soils are determined by pedological as well as viticultural factors.

The viticultural suitability of a location depends on general climatic conditions, as well as aspect and inclination of the land surface towards incoming solar radiation. The energy gain from solar radiation depends on the angle of incidence of the incoming rays. Maximum gain is achieved when the surface is perpendicular to the incoming solar radiation. At mid-latitudes these optimum conditions are only found on slopes. Generally, south-facing steep slopes below the local orographic and climate limit are most likely to fulfill the radiation requirements of the vine. The energy budget within a vineyard also depends on local climatic conditions such as exposure to cooling katabatic winds. The suitability of a site for viticulture also depends on soil properties such as aeration (rapid warming in spring, waterlogging), water budget (risk of drought, rise of groundwater table into rooting zone) as well as rooting depth. These factors are the reason why specific landscape elements are preferred for viticulture.

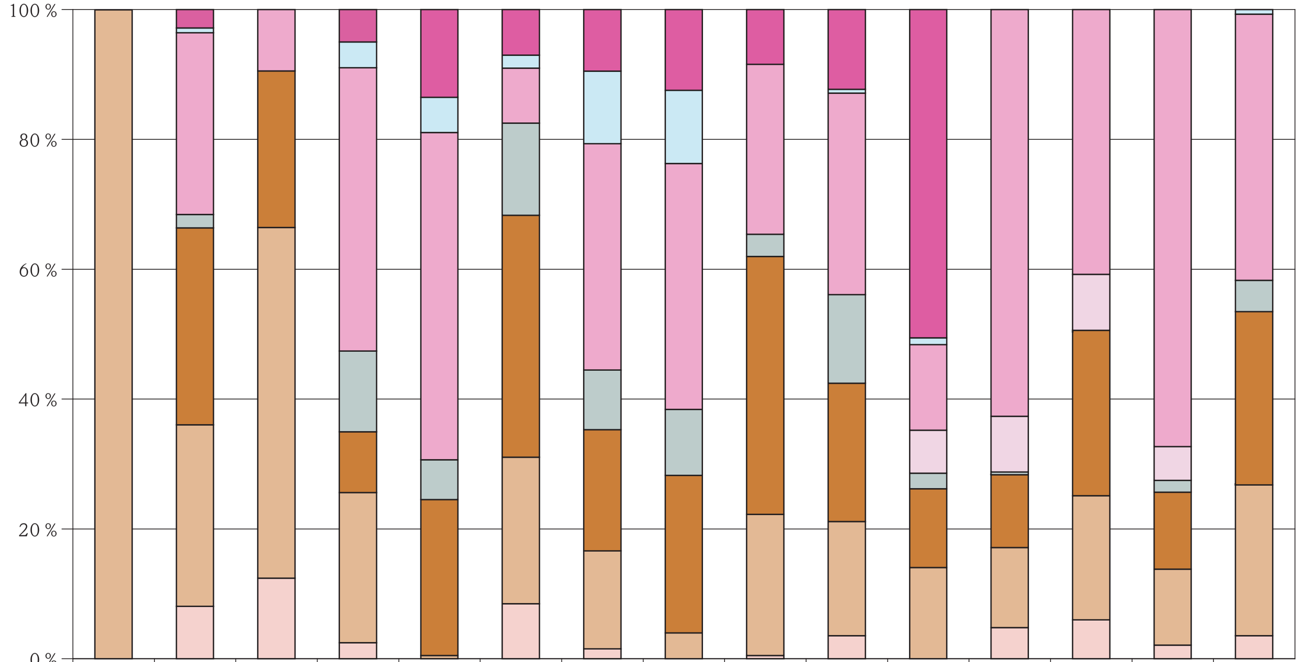
As already described above the variety of soil distribution within a viticultural region is very heterogeneous. This complexity is also found within single wine locations. The general distribution of soil groups within a location is presented in the soil map. The proportional distribution of soil groups within the wine locations is shown in Fig. 3. The results show a clear prevalence of Soil Groups II, III and V. However, at the local level other groups may dominate. For example, the soils within the clay and marl locations of the Maingau all belong to Soil Group VII. The overview shows the fundamental heterogeneity of the individual locations, an aspect of great importance when seen from the terroir point of view because of the intense effect of soil on the taste of the wine.

An overview of the soil inventory and the individual characteristics of the viticultural regions will be discussed in the next section.

The largest area under cultivation is located in the **Upper Rheingau** between Wiesbaden and Rüdesheim. The area is 3 – 6 km wide and extends over a distance of 25 km, parallel to the Rhine. This landscape of gentle hills is increasingly constricted towards Rüdesheim until cut off by the Taunus Mountain ridge near Assmannshausen.

The south-facing slope from the foot of the Taunus ridge to the river has been carved into long ridges and vales by tributaries. Geologically, most of the Rheingau is part of the Mainz Basin, a Tertiary marine basin filled with sands, clays, marls and limestone deposits. There is no morphological evidence of the main tectonic fault line between the Mainz Basin and Taunus Mountains. However, across the fault the geology changes from the sediments of the Mainz Basin to sometimes deeply weathered phyllite, sericite-gneiss and schist of the Rhenic Mountains. The landscape west of Rüdesheim consists of the quartzites and sandstones of the Taunus Mountains. The slope is partially covered with a series of old terraces where the Rhine has deposited sand and gravel.

While these rocks make up the underlying geology of the region, they do not usually form the parent material for soil formation. The most important parent material in this region is loess and sandy loess – fine dust removed by wind from the Rhine gravel beds during the pleistocene, and deposited in the vicinity. The thickness of



	no collective vineyards	Burgweg	Steil	Erntebringer	Gottesthal	Mehrhölzchen	Deutelsberg	Honigberg	Heiligenstock	Steinmächer	Daubhaus	Rott	Wolfsmagen	Schlossberg	no collective vineyards Gross-Umstadt
	Rheingau										Maingau	Hess. Bergstrasse			
Soil group VII		21,9		36,6	39,6	24,7	29,6	31,5	18,9	88,9	205,4				
Soil group VI		5,9		29,3	15,9	6,9	35,6	28,6		4,3	4,3				0,8
Soil group V		217,4	9,1	320,9	147,5	29,8	111,0	96,0	58,5	225,0	53,5	108,7	66,4	230,2	47,4
Soil group Va		16,1									26,9	15,0	14,2	17,8	
Soil group IV			23,1	91,6	18,0	49,9	29,2	25,8	7,6	98,7	9,8	0,6		6,2	5,6
Soil group III		235,8	51,7	68,7	70,3	130,8	59,3	61,5	88,8	154,5	49,3	19,6	41,6	40,6	30,8
Soil group II	4,3	217,2	11,9	170,2	1,5	79,2	47,9	10,1	48,6	127,2	57,0	21,3	31,1	40,0	26,8
Soil group I		62,8		18,1		29,8	4,8		1,1	25,7		8,2	9,7	7,2	3,9

Fig. 3. Distribution of soil groups in collective vineyards (proportion in collective vineyards – Graph; area in ha – Table).

the loess gradually decreases from the river towards the top of the Taunus mountain range. On the one hand, this pattern may be explained by a decrease of the wind-borne load with increasing distance from the river. On the other hand loess was transported down the steeper slopes by subsequent erosion. Solifluction was a common phenomenon on the steeper slopes during the various phases of the ice age. In the summer months, the thawed surface soil and rock debris slid downwards over the frozen subsoil carrying with it the incorporated loess deposits.

These mudslides were inactivated with the onset of the current warm period. Today they are widespread and cover the higher and steeper parts of the region, forming the parent material for soil formation.

Finally, it is necessary to point out that the soils of the valley floors are formed on young fine-grained river and stream deposits (floodplain deposits) that cover the gravel beds.

The natural soil communities on the loess deposits of the Rheingau are dominated by deep, fertile luvisols with a balanced water budget. Thousands of years of arable farming and viticulture on locations with high erosion potentials has resulted in an almost complete loss of the soils formed during the holocene. Today these locations are characterized by calcareous lepti-terric anthrosols. The eroded soil material was deposited as colluvium at the base of slopes and in dry valleys. The soils found on mudslides mainly consisting of debris from the underlying tertiary sediments vary according to the type of material: dry cambisols on sand, vertisols on clay and calcaric regosols on the marl and limestone debris. Phyllite weathers to a clay saprolite, which has been preserved chiefly on the more level locations. The soils formed on this parent material all tend to suffer from periodic waterlogging. The typical soil on these locations is a nutrient-deficient stagnosol. These waterlogged soils cover large areas above the viticultural regions in the Taunus Mountains.

The exposed rocks of the steep slopes were fractured by ice and the debris was transported downhill by solifluction. Typical soils of these stony debris flows are dry cambisols with shallow to intermediate rooting depths and unbalanced water budgets. The valley locations are characterized by nutrient-rich gley- or fluvisols depending on the groundwater level.

As a consequence of the generally favorable climatic conditions of the Rheingau, most slopes along the river Rhine are used for producing wine. This even includes some parts of the level, lower river terrace covered with floodplain sediments. The utilization of the land diversifies considerably nearer to the (cooler) Taunus Mountains. The cross-sectional profile of the N-S orientated ridges is distinctly asymmetrical. The W-facing slopes are so steep as a result of undercutting by the eastward drifting streams that only a thin layer of loess could be preserved here. The underlying tertiary marls, clays and sands are exposed and form the parent material for soil formation. Despite the predominance of inferior soils (Soil Group VII), these locations are exclusively used for viticulture because of the favorable exposure of the slopes. This contrasts with the level tops, where viticulture is restricted to lower elevations despite the prevalence of valuable luvisols on loess. The gradual E-facing slopes of the ridges are covered with thick loess deposits and are used for agriculture.

Towards the Taunus mountain range, beyond the boundary of the Mainz Basin, viticulture is limited to the S to SW-facing slopes with stony cambisols on phyllite debris flows with low loess contents. Peneplanation areas contain mostly stagnosols formed on saprolith.

The evident preference of nutrient-poor, dry and stony cambisols on debris flows over phyllite between Frauenstein and Hallgarten and over quartzite and sandstone between Rüdesheim and Assmannshausen underlines the outstanding importance of aspect and slope as viticultural land use criteria. This also explains the relatively large proportion Group VII soils used for growing wine. These soils pre-dominate the sunny sides of the valleys. In contrast, the favorable luvisols on the more prevalent loess locations are underrepresented because they are mostly found on the peneplanation areas and E-facing slopes. The loess-dominated locations that are used for viticulture are situated along intermediate or steep slopes. As a result of the high erosion potential, the common soil on these locations is a calcaric regosole (Soil Group V).

The soil distribution of the **Middle Rhine Valley (Lower Rheingau)** differs completely from that of the Upper Rheingau. The predominant rocks are quartzites, sandstones and schists of the Taunus Mountains. The solitary remains of river terraces are found in the side valleys where the deposits have often been incorporated in mudslides and distributed over the slope. The landscape is characterized by rock exposures, at best covered by leptosols. These marginal winegrowing locations on bare rock are no longer in production and some areas show relicts of historical soil erosion. The dominant parent material in the region consists of shallow debris flows. On the exposed slopes these are mainly composed of the underlying rock with small amounts of incorporated loess. The cover is usually less than 0.5 m thick. The typical soil is a stony, nutrient-poor, dry cambisole. This contrasts with the thick loess accumulations of the river mouths (side valleys) and concave sections of the slopes, where luvisols have developed. An extensive loess covered area with calcaric regosole, sometimes formed on mudslides is located on the lower slopes SE of Lorch (Soil Group V). Otherwise loess is only found in smaller areas on gradual, shielded locations. The floodplain deposits of the side valleys consist of eroded material from the catchment area. The characteristic soils are waterlogged gleysols to thick, nutrient-rich fluvisols.

Site exposure to direct solar radiation is especially important for selecting a suitable site in the narrow Rhine valley of the Lower Rheingau. Despite the laborious working conditions the preferred locations are situated along the optimally exposed slopes. Only the steepest terrains covered with leptosols are avoided altogether. During the construction of the terraces, soil material was added to the frequently shallow soils to increase the rooting depth. This is why this region is dominated by Group II soils, which cover over 50 % of the vineyard site “Steil” (“steep”).

Viticulture in the **Maingau** is restricted to the steeper slopes of the Main and Wickerbach valleys and more rarely on the level, loess covered river terraces above. Geologically, the Maingau is also part of the Mainz Basin and the rocks below the surface are similar to those found in the Rheingau. These rocks are exposed along the slopes where they are covered by a thin veil of loess. The characteristic soils of the region are therefore Group VII with clay and marl soils, which cover nearly 50 % of the surface. Less frequent are the dry sandy and gravelly soils (regosols and cambisols) on river terrace deposits incorporated into mudslides. Luvisols have developed on mudslides containing a large proportion of loess. However, many of these soils have been eroded so that even the calcaric regosols on loess are found on about 13 % of the surface area. Consequently, the base of the slopes is covered by calcareous colluvium. About 6 % of the area is covered by aeolian sand with deep but dry arenosols (Soil Group Va).

The **Bergstrasse** is the eastern margin of the Upper Rhine Rift Valley towards the Odenwald mountains. The underlying rocks, predominantly magmatites of the Crystalline Odenwald are only exposed on the slopes, shoulders and hilltops. In the middle and lower slopes these rocks are covered by sandy loess and loess with local occurrences of nutrient-rich luvisols with a balanced water budget. The combined effects of a high erosion potential of the sandy loess, steep terrain and centuries of continuous agricultural use have often led to the complete loss of the primary luvisols, which have been replaced by calcareous regosols. The eroded soil material accumulated as colluvium at the base of the slopes, small depressions and valleys. The loess-dominated deposits with Group V soils cover over 60 % of the vineyard site “Rott” and “Schlossberg". This is the largest occurrence of these soils in the viticultural regions of Hesse. The calcareous aeolian sand deposits at the base of the Upper Rhine Rift, are also part of the soil distribution. The typical arenosols of the new subgroup Va have developed on aeolian Sand with clay ribbons (lamellic horizon) in the underground. Continuous farming activity accounts for the current presence of calcareous regosols and mostly colluvium on eroded locations. The regosols are usually dry. The exposed slopes and shoulders are usually covered with solifluction layers dominated by stones. Typical soils are dry leptosols and cambisols. Extreme locations typified by Group I soils are quite rare, whereas Group II soils cover around 12 % of the vineyard location "Rott" and "Schlossberg" and over 20 % of the location "Wolfsmagen".

The very small and scattered **viticultural region Gross and Klein-Umstadt** is located near Dieburg at the northern edge of the Odenwald. This landscape of gentle hills is blanketed with thick loess deposits, which cover the down-dropped magmatic rocks of the Odenwald. The primary luvisols have all been degraded to calcareous regosols. Small depressions and valleys have been filled with the eroded soil material, which forms the parent material for colluvisols. About 40 % of the wine-growing area is covered by Group V soils. The underlying rocks penetrate the loess cover in the steeper locations. However these are covered by mudslides with cambisols (Soil Group II) or multi-layered luvisols (Soil Group III). These soils cover about 25 % of the viticultural region.

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