Detailed mapping of geocomplexes in the vineyard landscape

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Abstract

Viticultural landscape is a valuable part of the cultural landscape – it was created by the long-term impact of human activities on areas with suitable environmental conditions for the development of vineyards. A geoecological research within an example study of vineyard landscape was realised in choric and topical geographical dimension in the Doľany vicinity. Georelief was selected as a leading factor of regionalisation at the level of geochores. Information about soil-forming substrates and land cover on a topical dimension was specified within a detailed research of the terrain. Overall, five basic types of geochores and 58 types of geoeological complexes were earmarked. The most frequent occurrence of vineyards was on the alluvial co-ones and slopes of the Malé Karpaty Mts. As a part of the detailed research of the soil, we further characterized location conditions of different grape varieties in the Fosandle and Grefty localities.

Key words
Doľany, geoecological research, Slovakia, vineyard landscape

Introduction
Detailed research of agricultural landscape is still an actual topic of landscape ecology. Human impact has been changing the landscape for centuries. Landscape changes are an expression of the dynamic interaction between natural and cultural forces in the environment (Antrop, 2005). These changes significantly affect the landscape’s ecological stability (Lipský, 2001; Ivan et al., 2015), as well as biological (Löfvenhaft et al., 2004), environmental and aesthetic value (Nassauer, 1995; Pătru-Stupariu et al., 2015). In Central Europe, agricultural processes belong to important drivers of the land use changes (Muchová and Petrovič, 2010; Špulrová et al., 2011; Kopecká et al., 2012; Jusková and Muchová, 2013; Opršal et al., 2013; Havlíček et al., 2014; Jusková and Muchová, 2014; Sklenička et al., 2014; Grešlová et al., 2015; Lieskovský et al., 2015).

Viticultural landscape is a valuable part of the cultural landscape – it was created by the long-term impact of human activities on areas with suitable environmen-
tial conditions for the development of vineyards (Supu-

ka et al., 2011). Viticultural landscape has a remarkable
landscape image, the importance for ecological stabil-
ity and physiognomically it is a distinctive type of land
cover. Environmental conditions also form a significant
part of the terroir.

The term ‘terroir’ is used very often globally,
and it means the influence of natural factors, especially
concerning geology, soils, relief and climate, suitable vine
variety for the site and also the technological procedures
of wine makers. Studying various parameters of terroir
altogether is very rare and has become a subject of inter-
est (VAN Leeuwen et al., 2004). Over the past few years,
geographic information systems have been used for the
accurate mapping of vineyards (Matečný, 2014). In
this context, modelling of relief indices for spatial dif-
fertiation of microclimatic conditions has also played
an important role (Miklós et al., 1991; Matečný et al.,
2010). Modern complex physical geographical (geo-
ecological) research is focused on a detailed descrip-
tion of formation, evolution, and operation of geosys-
tems at a detailed topic level, with relevant landscape
components being represented (MINÁR, 2003; FAŤAN
et al., 2009; Čech and KUNÁKOVÁ, 2012; BARRÍK
et al., 2014). Many Slovak wine producers are aware of
the importance of terroir and are endeavouring to produce
wines from grapes that are bound to a specific locality.
Therefore more attention has been paid to parameters
such as bedrocks, soils and climate in vineyards (Döró
et al., 2010).

Over the last few years, the quality of Slovak wine
has improved; as confirmed by the many gold medals
won at various prestigious wine competitions around
the world. Slovak wine is now comparable to fine world
wines in terms of its quality and sensorial properties.
On the other hand, vineyard areas are still being re-
duced (LAUKO et al., 2013; HANUŠIN and ŠTEFUNKOVÁ,
2015). The wine region of the Malé Karpaty Mts has
very good soil, climate and ecological conditions for
wine production (Čerňanský and KUHN, 2012). Yet
vineyards are being abandoned in this region because
of the current EU Agricultural policy (LIESKOVSKÝ
et al., 2013). Viticulture participates in the conserva-
tion and appropriate usage of agricultural soils, and in
the evolution of ecologically balanced land with economic
benefits.

The objective of our research is to investigate geo-
systems (with relevant natural components of terroir)
in the surroundings of the vineyard village Doľany in
the wine region of the Malé Karpaty Mts. We will use
the methodology of geocological research and detailed
mapping in both choric and topic geographical dimen-
sions. Maps of choric dimension characterize wider
(horizontal) relationships in the vineyard landscape,
while research in topical dimension yields basic infor-
mation on natural components of terroir in large scale
and their spatial distribution.

Material and methods

Study area

The investigated area in the surroundings of Doľany (Fig. 1) occupies the foot of the slopes of the Malé Karpaty Mts with adjacent highland belonging to the Podunajská nížina lowland. It is an area with a significant history of grape growing. The investigated area covers 1,196.16 ha and is located between 188 and 472 m asl. The vineyards in Doľany, belonging to JM Vinárstvo Doľany (where detailed field research was carried out), cover an area of 7.56 ha and are located at the foot of Malé Karpaty at the boundary of cadastral areas of the boroughs Doľany and Dolné Orešany, at an altitude of 236 to 256 m asl.

Fig. 1. Localization of study area.

Doľany, sometimes also called Ompitál by the lo-
cals, was one of the oldest German colonies under the
Malé Karpaty Mts, up to the first half of the 18th cen-
tury, when people started to use the Slovak language.
Since 1608, Doľany has been an important wine town.
Wine trade, which was dependant on the area of vine-
yards and the grape harvest, was especially important
for the development of the town. According to the data
from 1858, the vineyards occupied 98.5 ha of the total
2,206 ha belonging to the borough. White grape variet-
ies Cirifandl and Lampart were grown there. At the end
of the 19th century, vine phylloxera spread throughout
the wine region, resulting in the loss of the vineyard
area in the following years. In 1924, during the inter-
war period, the area of vineyards was only 21 ha. After
World War II, the price of wine had increased, which resulted in the expansion of viniculture. In 1950s, the collectivisation caused not only the change of the wine grape land ownership, but also influenced the level of viniculture. The co-operative viniculture shifted from growing hybrids to growing varieties such as Grüner Veltliner, Irsay Oliver, Burgundy, Silvaner. The change of situation after the fall of communism was manifested by initially good results – in 1992, the 89 ha of vineyards produced an average yield of 5.21 tons of grapes per hectare. In the following years, the wine production decreased, which was resolved again in 1996 by leasing the co-operating vineyards to private entrepreneurs (DUBOVSKÝ et al., 2002).

Geocological research and mapping of ecosystems

The geosystems research consisted of several stages – the preparatory phase, field research and the final phase. The research process was based on the geological methodology according to the works of MINÁR et al. (2001) and ČECH and KUNÁKOVÁ (2012), with emphasis on mapping in large scale.

The preparatory phase of the research consisted of collecting data and studying available materials around the observed area and its surroundings. The basemaps were studied for each relevant component of the country. The basemap of the lithology of the observed area was the Geological map of the Slovak Republic at scale of 1:50,000, available on the website of the State geological institute of Dionýz Štúr, and an additional source was a regional geological map (POLÁK et al., 2011). The basemap for the georelief characteristic was The Basic map of the Slovak Republic at 1:10,000. On the basis of contour lines, we have determined elementary forms of relief, to which the attributes according to the legend of the morphographic-positional types of relief have been assigned (TREMBKOŠ in MINÁR et al., 2001). In the case of transport slopes, attributes were extended to direct transport slope, concave transport slope and convex transport slope, from the viewpoint of the curvature contour line. The digital elevation model was created from the contour map by the tool Topo to raster with the size of the cell 10 m in the ArcGIS environment. Other rasters of slope, aspect and insolation of land were derived from the digital model of relief.

Agriculturally used soils were characterized on the basis of the map service of the National Agriculture and Food Centre, through maps of evaluated soil-ecological units at a scale of 1:5,000 (SOIL PORTAL, 2015). In forest areas, the data were derived from the WMS service of the NATIONAL FOREST CENTRE (2015). To unify the soil classification from these sources, a comparison of National Forest Centre soil systematic with the Morphogenetic classification system of soils of Slovakia was used. The information about climate characteristics was provided by the Slovak Hydrometeorological Institute for the period 1981–2010, from the stations, located nearest to examined locations. The average monthly rainfall totals were processed from the rain gauge stations in Dolné Orešany for the period 1981–2010. Similar data about air temperature in Doľany in 2014 were provided by the vine-dresser of wine-making JM Vinárstvo Doľany, which was compared with the average air temperature at the station in Slovenský Grob in 2014. Aerial scans by Google Earth from 2013 were used to characterize land cover. Particular classes of land cover were assigned on the basis of the edited methodology and CORINE land cover legend at the 4th hierarchical level at a scale of 1:50,000 according to authors FERANEC and OTÁHEĽ (1999). Land use of the examined area was mapped at a scale of 1:10,000, therefore we set the minimal size of the mapped area to 0.1 ha. Because the work was focused on vineyard landscape, two classes of land cover evolved from the original methodology (used and unused vineyards). In the further stages of research, we concentrated on mapping habitat conditions in the earmarked categories of vineyards. Potential natural vegetation was presented according to the map of potential natural vegetation (MAGLOCKÝ in Atlas krajiny, 2002).

In terms of methodology by authors FALŢAN et al. (2011), a map of geocomplexes at the level of geochrones was created for the whole examined territory, meaning that relatively homogenous areas where the horizontal relationships among geotopes and their groups were examined (MIČIAN, 2008), with an interpretation measure of 1:10,000. In our case, as a leading factor of regionalization, georelief at the level of mezoform was selected. Furthermore, information about the bedrock, soil type and subtype, relief insolation and potential natural vegetation was examined.

The realization of detailed field geocological research was limited by the availability of particular vineyards, subject to the various owners and unsettled owner relationships. Our research was conducted on estates belonging to the JM Vinárstvo Doľany. Particular research points and borders of the examined vineyards were localized by a GPS device. During our research, the data gathered in the preparatory phase of research were verified. By characterization of pedosphere, the soil unit and soil category were set (soil type and subtype). Thickness, granularity, soil skeleton, composition, size and form of skeleton, colour, spotiness, humidity, hardness, plasticity, structure and biological activity were set for each horizon. Moreover, samples from depths of 20–40 cm and 50–70 cm were taken from particular soil probes for chemical testing, to find the content of carbonates (titration method), nitrogen (Kjeldahl method) and pH reaction (STN ISO 10390). Concerning georelief characteristics, information about GPS location, altitude of each point, slope, orientation, meso-form of georelief, genesis, age and process demonstrations was presented. The biosphere characteristic
was set through real phytocenosis, potential phytocenosis, coverage and height in particular stages. Laboratory soil analyses were realized by the accredited laboratory of the Soil Fertility and Conservation Research Institute.

In the final phase of research, we concentrated on the creation of final maps of geochores types as well as types of geoecological complexes and insolation. By processing the results from our field research, we created a map of edited soil types and subtypes over the area of the examined vineyards. The results of the soil analyses and the data provided by vine-dressers were statistically processed in MS Excel. Relief insolation maps were created from the digital relief model using an Area Solar Radiation tool every half hour, each 14th day of the year. Random settings (except for the setting of the diffuse model type) were allowed in the parameters of insolation (the chosen option was most commonly overcast). The outputs of the detailed research were processed in the ArcGIS 10 Environment.

Results

The examined area contains five types of geochores, illustrated in Fig. 2. The dominant areal representation has geochores of the alluvial cones on proluvial sediments where Cambisols have formed, and potential natural vegetation is represented by Carpathian oak-hornbeam forests. More than half of the vineyards (57.7%) in the examined area are located on this geochores. A large percentage of vineyards (37.7%) is situated on the geochores of slopes that consist mainly of shist where Cambisols have formed and potentially natural vegetation is created by Carpathian oak-hornbeam forests. Some vineyards extend to both of the mentioned geochores, particularly to the valley geochores. It follows that vineyards are most often located on alluvial cones, transport and foot slopes of the Malé Karpaty Mts. The larger slope and mainly south-eastern orientation of the relief influences the incoming solar radiation power. Solar radiation is an important positioning factor. Relief insolation in the Doľany area is presented in Fig. 3, where the average insolation value is 1,082.9 kWh/m² per year. The areas with the lowest incoming solar radiation power are in particular north-eastern and eastern valleys slopes and slopes with a western exposition; on the contrary the highest values of insolation occur on the south-western oriented slopes with a larger angle. In the study area, the slopes with south-eastern orientation outweigh the cardinal points overall. The vineyards extend over an area with insolation values from 1,026.4 to 1,168.9 kWh/m² per year. High insolation values were reported at vineyards, not in use, as well as in some south oriented localities with steeper slopes on forest land.

Fig. 2. Landscape structure of geochores.

Fig. 3. Insolation of relief.
The results of the geotopes research were processed for the areas of vineyards. Together, under the framework of 6 types of geochors, 58 types of geocological complexes were classified by using the georelief as the leading factor of regionalization; the most commonly represented are listed in Table 1. From the viewpoint of localization of vineyards, these complexes have beneficial assorted substrate, which contains worked aluminous and sandy gravels and aluminous-chiselly down-slopes. The substrate was the basis for forming the medium to hard skeleton soils, which is important for the wine grape, mainly when taking nutrients from the soil. A very important criterion is the ease of availability to these vineyards when in need of cultivation. On the contrary, the types of geocological complexes that have good substrate potential and high insolation of 1,125.1 to 1,175 kWh m⁻² per year (in the 5th and 6th categories of insolation), have not been used recently as vineyards, mainly because of their poor availability.

Table 1. The most frequent types of geosystems

<table>
<thead>
<tr>
<th>Code</th>
<th>Lithological complex</th>
<th>Landform</th>
<th>Insolation-category</th>
<th>Soil type</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>Proluvial sediments</td>
<td>Cone</td>
<td>2</td>
<td>Cambisol</td>
<td>25.86</td>
</tr>
<tr>
<td>56</td>
<td>Proluvial sediments</td>
<td>Cone</td>
<td>3</td>
<td>Cambisol</td>
<td>20.69</td>
</tr>
<tr>
<td>45</td>
<td>Deluvial sediments</td>
<td>Foot slope</td>
<td>3</td>
<td>Cambisol</td>
<td>12.07</td>
</tr>
<tr>
<td>46</td>
<td>Deluvial sediments</td>
<td>Foot slope</td>
<td>4</td>
<td>Cambisol</td>
<td>8.62</td>
</tr>
<tr>
<td>42</td>
<td>Proluvial sediments</td>
<td>Foot slope</td>
<td>4</td>
<td>Cambisol</td>
<td>6.19</td>
</tr>
<tr>
<td>51</td>
<td>Fluvial sediments</td>
<td>Floodplain</td>
<td>2</td>
<td>Fluvisol</td>
<td>6.90</td>
</tr>
<tr>
<td>04</td>
<td>Breccias and conglomerates</td>
<td>Erosion-denudational slope</td>
<td>4</td>
<td>Rendzina</td>
<td>5.17</td>
</tr>
</tbody>
</table>

The field research connected with sample collection at the examined area in Doľany was realized in vineyard localities Fosandle and Grefty (Fig. 4). The vineyard is located on an alluvial cone at an altitude between 236 and 256 m asl with a south-eastern exposition. The slope angle is from 1º to 7º. Geological bedrock is created by proluvial sediments, loamy and sandy gravels lay in the form of alluvial cones. According to the map of bonited soil-ecological units, there are Eutric Cambisols up to Luvi-Eutric Cambisols and Sagni-Haplic Luvisols in the examined vineyard. By using field research, we found an occurrence of cultivated Cambisols, Hortic Cambisols and cultivated Haplic Luvisols. At research points no. 1 and no. 2, cultivated Haplic Luvisols occur, Akp-horizon is present at a thickness of 35 cm, while no skeletons occur here, and the soils have loamy granulity. The dominant subsurface Bt-horizon contains up to 10% of skeletons and is enriched by translocated elements. Temporary B/C-horizon passes to bright substrate C-horizon (Fig. 5).

Fig. 4. Example of detailed soil map and localization of soil samples.
At research point nos. 4–6, Hortic Cambisols occur, with a dominant Akm-horizon, the skeletal content is from 25 to 70% and loamy granulity. Under the cultisoil horizon, the cambic Bv-horizon is located with high skeletal content (70–80%), which passes to substrate C-horizon. At research point nos. 3, 7 and 8, cultivated Cambisols occur. The cultisoil Akp-horizon has up to 30% of skeleton and loamy granulity. The dominant cambisoil Bv-horizon has a high content of skeletons (up to 70%) and loamy granulity. The sample of basic characteristics discovered in field research is listed in Table 2. In the vineyard area in Doľany, neutral soils occur – the pH value moves from 6.72 to 7.41. The content of nitrogen in the soil moves from 0.01 to 0.04%. The volume of nitrogen in the soil is low and medium. Appropriate nutrition will complement fertilization at poorer areas. The content of carbonates in the examined samples is less than 0.01%. Carbonate content in the soil is low due to site conditions, but overall the site is suitable for growing vines.

**Discussion**

Landscape-ecological parameters characterising the landscape structure, function and dynamics play an important role as an indicator of sustainable development (Kozová and Paudíšová, 2001). Agricultural geosystems belong to important parts of the present landscape structure. Growing permanent crops significantly affects the character of the landscape and creates a specific type of cultural landscape. The huge changes that our society and viniculture, went through after World War II posed a threat to the traditional vineyard landscape. The significant changes are not only in the area, size and vineyard agronomical practices – or the residential pressure of large cities such as Bratislava or Nitra – but also the changing lifestyle of young generations, who do not seem to be interested in viniculture or agriculture at all (Lieskovský et al., 2013). The complex safety of the vinicultural landscape should include soil safety, in an attempt to optimize the way the landscape is used and to be able to minimize soil erosion (Donaos et al., 2014).
Intensive land use changes affect not only the country itself but also progressively limit the activities of man. Man is presently the dominant factor in the forming of landscape and adapts it to its goals. Our work focussed on the physio-geographical aspects of the terroir, presenting an important factor of the localization of vineyards. The geographical characteristic of a particular location gives the vine a specific taste, which differs from vines produced in other regions. Therefore, the geographical attitudes to the study of viniculture, with an emphasis on terroir, are nowadays actual topics (Bonfante et al., 2011; Dougherty et al., 2012). The field research and application of GIS tools is an important part of the study of vinicultural geosystems. By creating a preliminary geocological map, we needed to choose appropriate base maps, or to create our own one by employing various methodologies (e.g. the map of elementary forms of relief). The methodology of creating the map of geosystems was influenced by the work of authors Minár et al. (2001); Čech and Kunáková (2012). These authors use the methods of the leading factor of georelief and the use of analytical maps within geocological research and the locating of geotopes. In our research, georelief was chosen as the main factor. We filled the created areas with further important information from the viewpoint of terroir – mainly bedrock, soil type and subtype and surface relief radiation.

Similar methods are successfully applied abroad, in countries with a long-lasting experience of wine cultivation. The area analysis of terroir in Valle Tellesina (southern Italy), has been evaluated by authors Bonfante et al. (2011). The terroir was classified on the basis of soil, value of radiation, index of crop water stress and detailed climatic research. The resulting terroir units were defined according to the suitability of vine production. The problems encountered were also analysed by Carey et al. (2008) in the Stellenbosch area in The Republic of South Africa. They defined the natural terroir units on the basics of the relatively homogenous characteristics of the topography, clime, geology and soils. As the leading factor, the morphographical characteristics of surface relief (altitude, slope, orientation) and soil type were used.

Generally, the bedrock of the soil only has an indirect impact on the quality of grapes and vine. Often bedrock is almost covered by the dominancy of the soil, topographic and climatic characteristics. The majority of nutrients are gained from depths of up to 0.6 m and water from depths of up to 2 m (Huggett, 2005). The investigation of soils under impact of traditional agricultural activities is an important topic of landscape ecological research (Slámová et al., 2015). Detailed field research and sample taking of terroir is necessary. According to our research, we found differences between the data from official basis soil maps and the real field environment. At the research area in the Doľany vineyards, according to bonited soil-ecological units, are where mainly Eutric Cambisols up to Luvi-Eutric Cambisols and Stagni-Haplic Luvisols are located. According to field research, the dominant occurrence of Cambisols has been proved, however, with the significant impact of cultivation. Cultivated Cambisols have been identified in three research points; more significant transformation by cultivating has been shown in the occurrence of Hortic Cambisols in three further research points. The change has been found only in the level of subtype in the location of Stagni-Haplic Luvisols – we identified Haplic Luvisols here, probably due to the soil cultivation and drainage. Within future research, it will be important to monitor microclimatic conditions of locations during long periods, except detailed soil analyses. For that, we need stationary research and placement of meteorological stations in the vineyards.

**Conclusion**

Basic relevant natural components of landscape representing physical-geographical aspect of terroir were described on the basis of detailed geosystems research in our work. Geocological research within an example study of vineyard landscape was realised in choric and topical geographical dimension in the Doľany vicinity. Georelief was selected as a leading factor of regionalisation at the level of geochores. Information about soil-forming substrates and land cover on a topical dimension was specified within detailed research of the terrain. Overall, five basic types of geochores and 58 types of geocological complexes were earmarked for location in the Doľany vicinity. The most frequent occurrence of vineyards was on alluvial cones and slopes of the Malé Karpaty Mts in terms of choric dimension. As part of a detailed research of soil, we further characterized location conditions of different grape varieties (Grüner Veltliner, Sauvignon, Irsai Oliver, Moravian Muscatel, Dornfelder, Cabernet Sauvignon) in the Fosande and Grely localities.

From the field research we found the occurrence of cultivated Cambisols, Hortic Cambisols and cultivated Haplic Luvisols with a predominantly neutral soil reaction and a nitrogen content of 0.04%. The application of our methodology provides useful information in terms of landscape and wine-growing practice. The most significant outputs include identification of different types of geocomplexes in the vineyard landscape. Combination of information about georelief, bedrock and soil cover in choric and topical dimension creates the basis for regionalisation and detailed identification of natural terroir units. With this, future research may take place focusing mainly on the study of the relationship between the physical and chemical properties of soil and microclimatic conditions of the habitat quality of the wine produced. A more detailed analysis of this issue.
would require the cooperation of several experts (oecologists, geochemists, etc.) from different disciplines. Analysis of natural landscape components and outputs in the form of geo-ecological maps can be used in environmental practice (landscape planning, evaluation of the carrying capacity of the landscape, evaluation of the potential or capacity of the landscape, etc.).

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