Soils of the southern slopes of the Villány Hills, SW Hungary

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The study area comprises the summit region, the southern slopes and the foothill region of the Villány Hills, SW Hungary. The range spans about 30 km in an east-west direction from the village of Hegyszentmárton to the town of Villány.

Fig. 1. Location of the Villány Hills

Lithology and topography

The Villány Hills form the southernmost hill range in Hungary. The hills are predominantly built of Triassic, Jurassic and Cretaceous limestone and dolomite, covered by Pleistocene loess at lower elevation (Lovász and Wein, 1974; Lovász, 1977), mostly below the summit region and at the foothills. In the summit regions, with the exception of the lowest elevation, the central part of the hills, limestone and dolomite are commonly found as outcrops (Wein, 1967). The range is built of uplifted and imbricated horsts. The sedimentary rocks that form the bulk of the range were thrust on each other in a thrust fault style forming blocks or "shingles" (Dezső et al. 2004; Sebe, 2017). The blocks are bordered by faultlines that dip to the west (Lovász, 1977). The blocks are tilted to the west, northwest, in the case of the Csarnóta block to the south and in the Szársomlyó block – to the north. Additional Mesozoic horsts and outcrops are found in the southern foreground of the range including the Siklós Castle Hill, the Beremend Hill and the Kistapolca Hill (Czigány, 1997). The summit regions are covered by shallow sediments and soils in a discontinuous fashion, while limestone caverns are filled in by Pliocene red clay (Lovász, 1973).

The highest point of the westernmost block is 268 m (Kopasz Hill). The limestone is common on the surface and a significant portion is exposed in the Csarnóta Limestone Quarry about 300 meters from the pass (Tenkes-csárda) where road 58 crosses the range. The average height of the block to the east (Csukma block) is around 340 meters with the Tenkes Hill (408 m), which is the second highest peak in the entire range. The summit elevation then decreases to about 240 m a.s.l. in the central, lowest part of the range (Város Hill block), north of the town of Siklós. In this block, the consolidated bedrock (limestone and dolomite) is only found in the surface of restricted areas, only in road cuts and in places where it is exposed by gullies and torrential creeks (field observation of the authors, 2017). To the east, the range again gains height to the Fekete Hill (358 m) and to the highest point of the entire range, Szársomlyó (442 m a.s.l.). The "devil's ploughfield" on the southern slopes of the Szársomlyó Hill is essentially the faces of the tilted limestone layers that dip to the north. Loess cover is only found in foothill regions, both on the northern and the southern sides of the hill (Lovász and Wein, 1974, Czigány, 1998).

Profile 1 – Endocalcaric **Cambisol** (Siltic, Ochric)

Localization: Southern slope – inclination 10°, under closed canopy forest, 205 m a.s.l., **N** 45°52'45.19" **E** 18°18'57.67"

Morphology:

Ah – 0–10 cm humus horizon, silt loam, very dark grayish brown (10YR 3/2 – moist) angular–subangular, blocky and granular fine–very fine structure, many roots, gradual and smooth boundary;

Bw – 10–40 cm, *cambic* horizon, silt loam, dark yellowish brown (10YR 3/4 – moist), angular–subangular blocky, fine structure, few roots, gradual and smooth boundary;

BC – 40–65 cm, transitional horizon, silt loam, dark yellowish brown (10YR 4/4 – moist), angular blocky, medium structure, few roots, gradual and smooth boundary;

C – 65–(80), parent material, loess, silt loam, light olive brown (2.5 Y 5/4 – moist), angular blocky, fine–medium structure;

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		2.0–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	0.002–0.001	<0.001	
Ah	0–10	0.0	0.0	5.4	11.3	41.6	17.8	9.4	5.7	2.8	6.0	SiL
Bw	10–40	0.0	0.0	2.1	8.6	34.6	12.6	8.2	9.2	5.6	18.9	SiL
BC	40–65	0.0	0.0	5.8	5.3	36.4	17.4	9.7	7.9	5.2	12.3	SiL
C	65–(80)	0.0	0.0	2.8	8.7	43.6	20.3	9.4	6.7	2.3	6.2	SiL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl	
Ah	0–10	85.1	7.0	6.8	1.53
Bw	10–40	9.3	7.4	6.9	1.44
BC	40–65	8.4	7.6	7.1	1.93
C	65–(80)	5.2	8.0	7.5	2.58

Profile 2 – Somerirendzic **Leptosol** (Humic, Siltic)

Location: karstic surface with limestone blocks on surface, edge of a quarry, summit, inclination 3°, 191 m a.s.l., **N** 45°53'06.2" **E** 18°13'53.7"

Morphology:

Ah – 0–15 cm, shallow humus rich horizon *mollic*, silt loam, dark brown (7.5YR 3/2), slightly moist, medium moderate granular structure, very fine abundant roots, gradual and smooth boundary;

ABw – 15–28 cm, *cambic* horizon with high content of calcium carbonates, silt loam, dark brown (7.5YR 3/3), slightly moist, medium moderate granular structure, fine abundant roots, abrupt and smooth boundary;

R – 28–42 cm, bedrock, (limestone);

CR – 42– 65 cm, *cambic* horizon, silt loam, brown (5.5YR 4/8, 7.5YR 4/4), slightly moist, coarse strong angular structure, many clay coatings, fine and very few roots, clear and wavy boundary;

R – 65 cm, bedrock (limestone, dolomite);

Heterogeneous spatial distribution due to limestone outcrops: Alternative horizonation: Ah, ABw, C, BwC, R

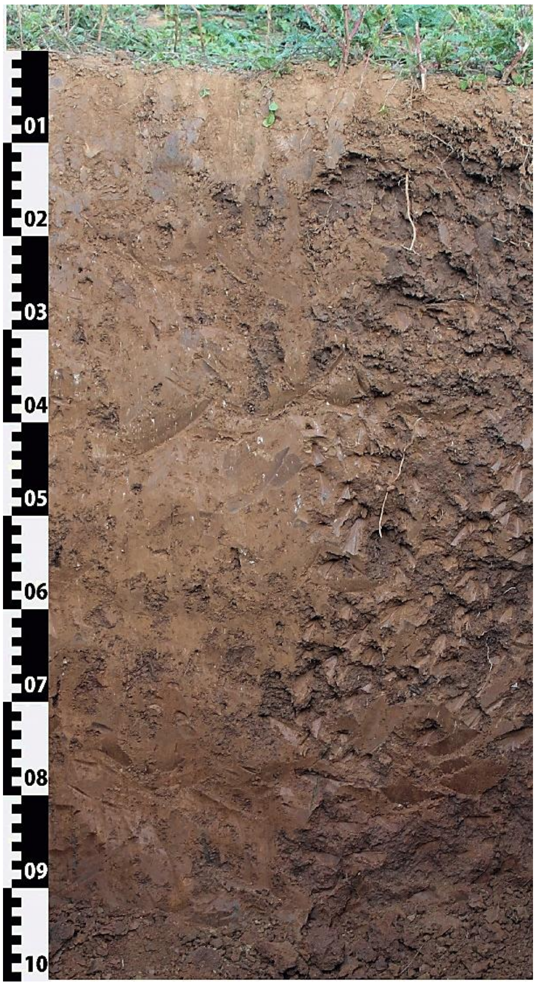
Table 3. Texture of profile 2

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		2.0–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	0.002–0.001	<0.001	
Ah	0–15	3.5	5.5	6.3	13.3	23.2	15.0	14.5	13.6	4.4	0.7	SiL
ABw	15–28	2.0	10.2	5.6	13.4	22.6	14.5	13.8	13.0	4.3	0.64	SiL
CR	42–65	10.8	3.2	0.5	5.2	14.3	23.7	26.1	11.3	3.2	1.8	SiL

Table 4. Chemical and physicochemical properties of profile 2

Horizon	Depth [cm]	OC [g·kg^{-1}]	pH		$CaCO_3$ [g·kg^{-1}]
			H_2O	KCl	
Ah	0–15	7.22	7.7	7.2	280.2
ABw	15–28	2.75	7.8	7.2	333.5
CR	42–65	0.13	8	7.4	804.6

Profile 3 – Haplic **Luvisol** (Aric, Colluvic, Cutanic, Humic, Pantosiltic, Protocalcic)
Localization: Mid slope – inclination 5°, fallow, formerly vineyard, 154 m a.s.l., **N** 45˚52'23.6'' **E** 18˚19'11.2''



Morphology:

Ap – 0–20 cm, humus horizon, colluvial material, silt loam, dark yellowish brown (10YR 3/4 – moist), angular–polyhedric blocky, platy, fine to medium, strong, compacted structure, distinct carbonates, clear and smooth boundary;

Ah – 20–40 cm, humus horizon, colluvial material, silt loam, dark yellowish brown (10YR 3/4 – moist), angular–subangular blocky fine–very fine structure, clear and smooth boundary;

Ah2 – 40–55 cm, humus horizon, colluvial material, silt loam, dark yellowish brown (10YR 3/4 – moist), angular blocky, fine structure, clear and smooth boundary;

Btg – 55–165 cm, *argic* horizon, colluvial material, silt loam, stagnic pattern – dark yellowish brown, dark brown, very dark grayish brown (10YR 4/4, 10YR 3/3, 10YR 3/2 – moist) angular blocky, fine to medium structure, clear and smooth boundary;

Bw – 165–200 cm, colluvial material, silt loam, dark yellowish brown (10YR 4/4 – moist), angular blocky, fine to medium structure, gradual and smooth boundary;

C – 200–(220) cm, silt loam, light olive brown (2.5 Y 5/4 – moist), distinct carbonates;

Table 5. Texture of profile 3

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–0.63	0.63–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	< 0.002	
Ap	0–20	0.00	0.00	13.0	5.6	14.5	28.7	13.7	11.7	8.9	3.9	SiL
Ah	20–40	0.00	0.00	11.2	15.9	19.0	27.4	9.8	8.0	5.9	2.8	SiL
Ah2	40–55	0.00	0.00	5.3	9.2	17.5	31.8	13.6	10.9	7.9	3.8	SiL
Bt	55–165	0.00	0.00	5.2	7.3	4.3	32.1	13.9	11.5	8.7	4.0	SiL
Bw	165–200	0.00	0.00	0.4	3.7	19.7	36.2	14.8	11.8	8.8	4.6	SiL
C	200–(220)	0.00	0.00	0.3	3.9	20.2	35.8	15.0	12.0	8.4	4.4	SiL

Table 6. Chemical and physicochemical properties of profile 3

Horizon	Depth [cm]	OC [g·kg^{-1}]	P [mg·kg^{-1}]	Conductivity [µS/cm]	Salts [m/m%]	pH		$CaCO_3$ [g·kg^{-1}]
						H_2O	KCl	
Ap	0–20	16.1	1070	344	0.03	7.1	7.4	89.6
Ah	20–40	14.0	741	314	<0.02	7.2	6.9	110.0
Ah2	40–55	11.1	592	311	<0.02	7.2	7.5	123.7
Bt	55–165	10.5	–	323	<0.02	7.2	6.9	90.9
Bw	165–200	10.3	–	310	<0.02	7.1	7.4	79.4
C	200–(220)	–	–	306	<0.02	7.9	7.5	

Profile 4 – Calcaric **Luvisol** (Aric, Colluvic, Cutanic, Humic, Pantosiltic)
Location: foot slope – inclination 3°, vineyard, slope 124 m a.s.l.,
N 45°52'05.6" **E** 18°18'34.4"

Morphology:

Ap – 0–20 cm silt loam, brown (10YR 4/3 – moist), strong angular blocky/granular fine structure, very few roots, clear and smooth boundary;

Ah – 20–60 cm, horizon, colluvic material*,* sandy silt loam, brown (10YR 4/3 moist), strong angular blocky structure, few roots, clear and smooths boundary;

Bt – 60–140 cm, *argic* horizon with distinct and common cutans, silt loam, brown (7.5 YR 4/4 – moist) strong angular blocky structure, very few roots;

Ck – 140–(160) cm, parent material with primary and secondary carbonates, silt loam, brown (7.5 YR 4/4 – moist) medium angular blocky structure, very few roots;

Table 7. Texture of profile 4

Horizon	Depth [cm]	Percentage share of fraction [mm]										Textural class
		> 2.0	2.0–0.63	0.63–0.2	0.2–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	< 0.002	
Ap	0–20	0.00	0.00	0.00	1.0	10.4	29.8	21.3	19.3	13.3	4.9	SiL
Ah	20–60	0.00	0.00	0.00	2.4	18.5	37.8	16.0	12.3	8.9	4.1	SiL
Bt	60–140	0.00	0.00	0.8	2.6	14.3	34.2	17.3	14.5	11.1	5.2	SiL
Ck	140–(160)	0.00	0.00	0.3	4.0	20.2	35.8	14.9	12.0	8.4	4.4	SiL

Table 8. Chemical and physicochemical properties of profile 4

Horizon	Depth [cm]	OC [g·kg^{-1}]	Conductivity [µS/cm]	pH		$CaCO_3$ [g·kg^{-1}]
				H_2O	KCl	
Ap	0–20	18.3	326	6.8	6.7	52.4
Ah	20–60	12.9	322	6.8	7.0	62.2
Bt	60–140	11.5	324	6.8	6.5	62.6
Ck	80–100	4.3	214	6.5	6.1	72.2

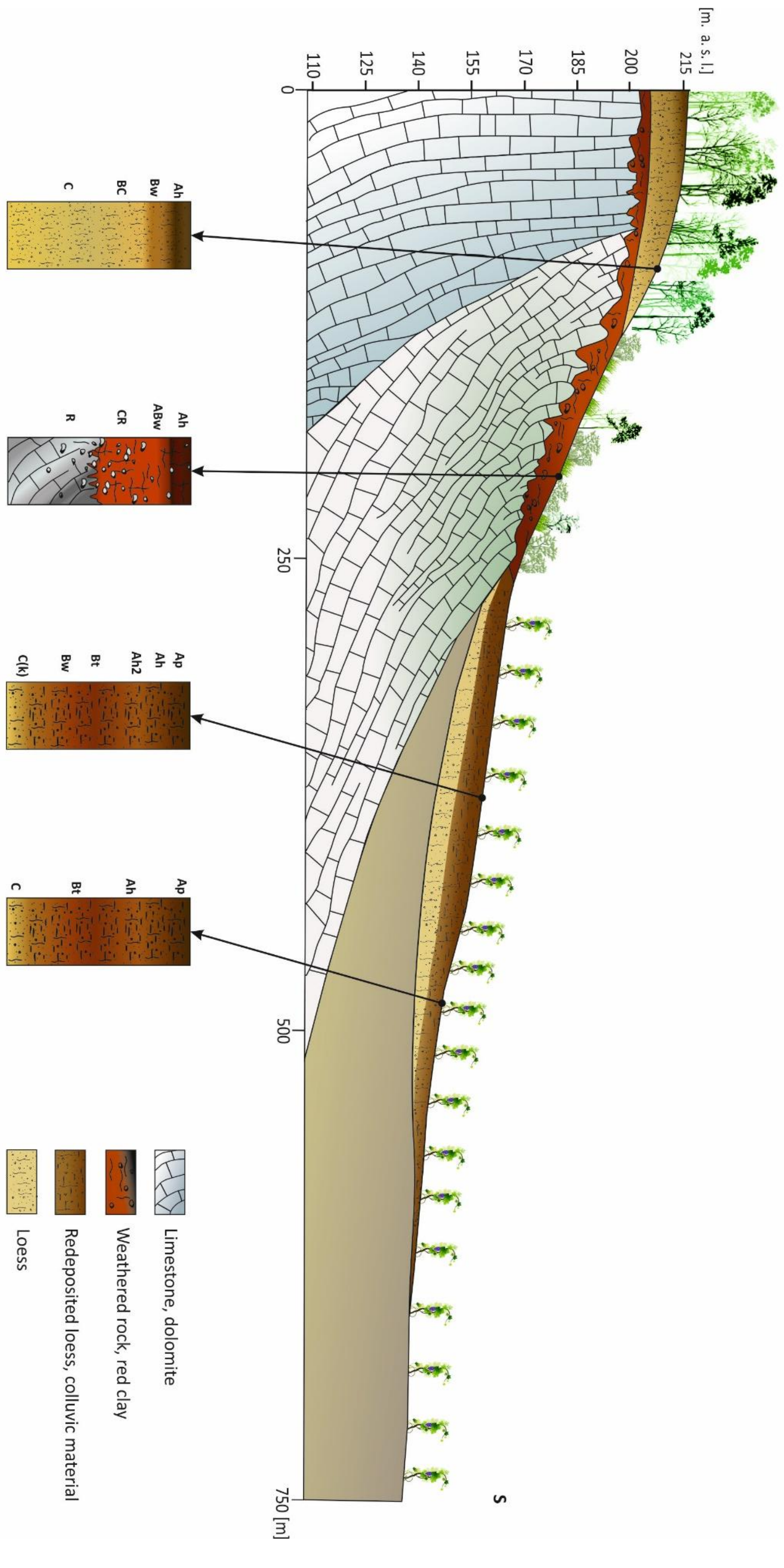


Fig. 2. Topo-lithosequence of soils in the southern slopes of the Villány Hills near Siklós, Hungary

Land use

There is a pronounced mesoclimatic and vegetational difference between the southern and northern slopes in terms of vegetation. The loess-covered northern slopes and summit regions are dominated by silver lime (*Tilia tomentosa*) hornbeam (*Carpinus betulus*), pedunculated oak (*Quercus robur*), Turkey oak (*Quercus cerris*) and, in some places, by beech (*Fagus sylvatica*).

The natural vegetation on the southern slopes is characterized by karstic wooded steppe (xerothermic wooded grassland) spotted, in places, with sparse rocky grasslands (Borhidi and Dénes, 1997). Trees in the wooded grasslands are dominated by South European flowering ash (*Fraxinus ornus*) and downy oak (*Quercus pubescens*), west of the village of Máriagyűd on the Tenkes Csukma blocks and the summit region of the Csukma block. A typical Mediterranean karstic steppe is found on the limestone surface of the southern slopes of the Szársomlyó Hill, with downy oak, South European flowering ash and invasive tree of heaven (*Ailanthus altissima*). The Szársomlyó is the only Hungarian habitat for some Mediterranean herbaceous plants, like *Trigonella gladiata* and *Colhicum hungaricum* (Lehmann, 1975; Borhidi and Dénes, 1997).

The loess-covered slopes on the southern side of the hills are extensively cultivated and used as vineyards (Tengler, 1997). To access the vineyards, unpaved dirt roads are used that are deepened into the loess and redeposited alluvial fans in the foothill loess sediments (Czigány, 1997; Czigány and Nagyváradi, 2000).

Climate

The study area belongs to the south-eastern Transdanubian Hills macro-region (Dövényi, 2010). The region is located in the temperate, fully humid climate zone with hot summers (Lovász, 1977; Kottek et al. 2006), with Mediterranean and sub-Mediterranean influence and arid continental influences. The average annual temperature is 10.8°C. The average temperature of the coldest month (January) is –0.5°C, while the warmest month is July with mean temperature of 22.5°C. The average total annual precipitation is around 680 mm in the region. The 30-year average value is 661 mm for the town of Siklós, 684 mm for Nagytótfalu, 694 mm for Villány and 701 mm for the town of Harkány (1971 to 2000 data, Hungarian Meteorological Services). Based on the meteorological data sets covering the period from the 1980s to 2010, February is the driest (32 mm) month, while the highest precipitation is recorded in June (83 mm) (Bötkös, 2006).

Soil genesis and systematic position

The investigated soil profiles exhibit high diversity of soil cover within the slopes of Villány Hills in SW Hungary. The soil sequence represents a typical series of soils starting from the summit covered by loess, which overlays the weathering products of limestone. In the steepest slope section, the loess cover is eroded, or was not even accumulated, hence the outcrops of the weathering limestone residuum and locally the rock. These are mostly protected areas, preserving the native vegetation cover, or therefore farming activities are precluded in the area.

The upper section and the most convex part of the slope is covered by ***Endocalcaric*** **Cambisol (*Siltic, Ochric*)** (IUSS Working Group WRB, 2015). This soil was formed under deciduous forest vegetation of silver lime (*Tilia tomentosa*) and black locust tree (*Robinia pseudoacacia*) (Fig. 2.). The texture in the entire soil profile is typical of soils formed on loess deposits, i.e. mainly silty loam (***Siltic***). The amount of organic carbon (>0.6%), structure and color of the A horizon is typical of the *mollic* horizon. Nevertheless, it does not meet the criteria for *mollic* according to the thickness (10 cm), therefore it was designated as the ***Ochric*** qualifier only. The carbonate content of the parent material is leached and depleted in the uppermost 60 cm, being less than 2%, the calcareous character is present only below 60 cm, therefore the ***Endocalcaric*** qualifier have to be added.

Profile 2 is located on a summit position on the rocky plateau of the Kopasz Hill, south of the village of Csarnóta. (Fig. 2). It represents a shallow soil with the *mollic* horizon developed on limestone outcrops (***Somerirendzic*** qualifier) and its loamy weathering products, containing sand and silt fraction, having the silty loam texture throughout (***Siltic*** qualifier) (Table 3). The diagnostic horizons in the discussed profile are: (i) Ah shallow humus-rich topsoil, (ii) a weakly-developed transitional ABw horizon rich in calcium carbonates, and (iii) heterogeneous parent material, which is composed of limestone blocks and boulders and its weathering product from Pliocene in the form of red 'clay' infillings. The most important feature of the profiles is the presence of coarse fragments in the subsoils and the shallow, carbonate-rich, humic surface epipedon. Due to the shallow profile and the proximity of the limestone and its weathered deposits, the carbonate content and the base saturation of the soil are extremely high, with 280.2 and 333.5 g kg^{-1} carbonate for the Ah and ABw horizons, respectively. The occurrence of soils with rendzic properties (Rendzinas in the Hungarian soil classification system) has already been pointed out by Lovász (1977). Due to the shallowness of the soil, it is uncultivated and only covered with a karstic wooded steppe dominated by South European flowering ash (*Fraxinus ornus*) and downy oak (*Quercus pubescens*).

Profile 3 – ***Haplic*** **Luvisol** ***(Aric, Colluvic, Cutanic, Humic, Pantosiltic, Bathycalcic)*** has been developed dominantly on colluvial material and translocated loess-paleosol deposits. The profile was excavated in an abandoned vineyard where cultivation was ceased in 2002. Soils in the vineyard were regularly fertilized and manured (***Humic***). The profile indicates a certain degree of leaching and clay translocation (***Cutanic***), as well as marked textural differences. Texture is dominated by the silt fraction (***Pantosiltic***). This part of the Villány Hills has been cultivated for the longest period of time, therefore colluvial and redeposited sediments have not only been formed by gravitational (derasional) processes but also by farming practices due to viticulture in the area since the Roman Ages (***Aric***). Moreover, the high amount of $CaCO_3$ with distinct secondary forms in the profile at a depth below 80 cm allows the identification of *calcaric* material. The carbonate content at this depth is high since the colluvial material is carbonate-rich too; due vertical leaching of carbonates, secondary carbonate concretions are also present. However, the carbonate content of the horizon does not meet the criteria of the *calcic* horizons, therefore it is ***Protocalcic.***

Profile 4 - ***Calcaric*** **Luvisol (*****Aric, Colluvic, Cutanic, Humic, Pantosiltic*****)** eventually had the same WRB classification and qualifiers as in the case of the soil in profile 3. This soil represents a relatively young soil developed as a consequence of *colluvic material* accumulation (***Colluvic*** supplementary qualifier). This material has been transported as a result of erosion from upslope since the area has been used as arable land in the past (***Aric***) (Lovász 1977; Tengler 1997; Czigány 1998). The texture of slope deposits is mainly silt (***Pantosiltic***). *Colluvic material* have a ***Humic*** character in the entire profile which is likely caused by the erosion of the topsoils further upslope. During the accumulation of the *colluvium,* certain periods of stabilization and low-degree erosional periods are identified in the profile. Nonetheless, the sporadic but rather torrent runoff and infiltration events caused heavy rainfalls triggered pronounced leaching and clay translocation processes in the soil (***Cutanic***). These soil forming processes are clearly represented in the profile and also reflected in the deeper dark horizons containing a high concentration of organic carbon. The contemporary surface horizons of these soils are enriched with humus by manuring and fertilization. However, their properties (color, structure) do not meet the criteria of *mollic* horizons. The soil in the profile is enriched with carbonates due to the colluvial processes and the proximity of loess deposits **(*****Calcaric*****).**

Soil sequence

The above-described transect (catena) shows a typical morpho-lithosequence for the Villány-Hills, formed according to its parent materials (limestone, loess and colluvium), surface topography and relief, and subsequently modified by agricultural activities and natural erosional processes. Properties of all analyzed profiles, with the exception of Profile 1, were strongly influenced by human-induced erosion. Profile 1 is a rather natural profile on a very gently sloping summit plateau. Although erosional processes are also observable here, they did not contribute significantly to the removal of the loess cover completely, only inhibited deeper soil development and organic carbon accumulation. Profile 2 is located in the erosional section of the investigated slope. The shallow soils here are discontinuous and scattered, altering with rock outcrops and hence bare surfaces, and do not form an uninterrupted soil cover. Formerly, profile 2 was also likely covered by loess, but we may also deduce that dust deposition itself was not possible here due to steep slopes, and soils have always developed on weathering products of limestone, and soils were also Leptosols in earlier times. Nevertheless, the presence of former and existing *cambic* Bw or even *argic* Bt horizons is also possible in the case of thicker weathered material, which could be eroded later as a consequence of human influence (deforestation, grazing etc.). Today profile 2 represents a strongly eroded stage: the shallow topsoil was likely truncated. Intense erosional and derasional processes must have occurred here in the past, probably due to land use (quarrying, vineyards), but also from natural reasons (steep slope, lack of dense forest cover). Lately, however, over the past decade or two (as of 2017), no-till farming practices have been prevailing in the region.

Soils developed on redeposited colluvial deposits dominate the middle and lower sections of the slopes (Profiles 3 and 4). Currently, the slope processes (primarily erosion) have been restrained by the introduction of grass vegetation and no-till viticulture, which also leads to improved organic matter characteristics of the studied profiles. In Profile 4, humus material accumulation was detected in the pedon, likely due to the resupply of organic matter in the form of manure and fertilizers.

The impact of erosion, horizontal translocation and redeposition according to the slope position is reflected in the systematic sequence of the described soils. Profile 1 has been markedly eroded and truncated, therefore profile development is poor, thus it was classified as **Cambisol**. Profile 2 with a shallow *mollic* horizon, but developed from material with a significant amount of coarse limestone fragments was classified as **Leptosols**. Profiles 3 and 4 are both of colluvial origin with distinct clay translocation after deposition of slope deposits and were classified as **Luvisols**. However, the marked impact of human activities in this catena is clearly visible in Profiles 1, 2 and 3, as the upper part of these profiles were eroded, redeposited and transformed into material with coarse granular moderate structure.

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