Soils of the abandoned gold and silver mining area on volcanic-hydrothermal rocks (Hungary)

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The study area is located in the northern part of the Tokaj Mountains, a Miocene volcanic mountainous area, where post-volcanic hydrothermal processes resulted in ore accumulation in quartzite veins. Gold and silver ore mining during the Middle- and Early Modern Ages considerably transformed the geomorphology of the surface and thus had a major impact on the soils too.

The slightly different character of the parent material and various types and intensity of human impact resulted in the increased diversity of soils, as natural soil profiles have also been preserved.

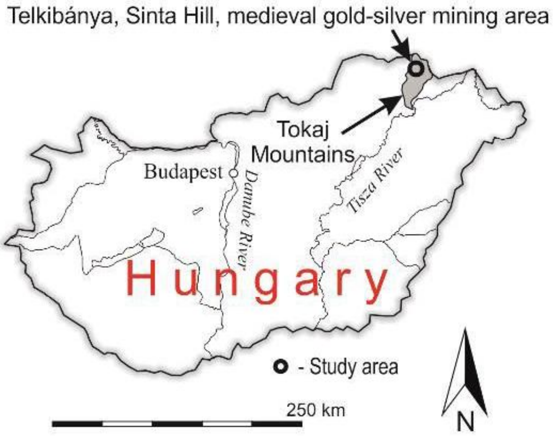


Fig. 1 Localization

Lithology and topography

The Sinta and Kecske Hát Hills form a 1.5 km long, 0.5 km wide, N-S oriented volcanic ridge at the southern margin of the hydrothermally altered andesitic area. The ridge is built of Miocene rhyodacite and partly covered by shallow marine marl and clay (Ilkey-Perlaky 1978; Molnár et al., 2009). The circulation of hydrothermal fluids caused intensive silicification, argillic alteration in NW–SE striking veins cutting through the host rocks (Zelenka and Horváth 2009). The 0.5–1 km long, 0.1–1m wide structures usually reaches 200 m in depth and contains gold and silver bearing ores (mainly sulphides). Large cavities in rhyodacite were filled with quartz crystals (up to 5 cm) forming the so-called geode. Long-term (10 million years) selective erosion (Zelenka et al., 2012) has prepared a harder, silicified ridge emerging 100 m above the surrounding valleys.

The mineral exploration in the gold-silver Telkibánya area started in the 12th century (Zelenka and Horváth, 2009). The open pit mining followed the ore bearing quartzite veins on the ground surface, while 100 m long adits quarried at underground levels (Zelenka and Horváth 2009). The yellowish, argillic vein material is well distinguished from the unaltered greyish dacite. Dense periglacial debris (0.5–1 m in thickness) of rhyodacite accumulated on the surface between the veins. Two NW-SE striking trails of open pits located on Sinta Hill were surveyed in 2016. The original morphology of pit holes was characterized by steep hanging walls. Waste of vein material and the host rock accumulated on the surface, which later fell down and partially filled the abandoned mine holes (Fig. 1b). The current average depth varied between 0.5 and 4 m. Some of the pits were reopened as a result of the resumption of mineral collection activity in the 1980s. Additionally, new shallow pits were excavated, tracing the occasional quartz filling the geodes of rhyodacite. The current landscape of the Sinta-Kecskehát Hills represents a special combination of primary volcanic and hydrothermal processes, coinciding with a special network of older and recent anthropogenic landforms.

Profile 1 – Skeletic Dystric **Cambisol** (Pantosiltic, Ochric)
Localization: Niche, medium slope - inclination 11°, deciduous forest vegetation, slope 453 m a.s.l.
N 48° 29' 48,42" **E** 21° 23' 16,76"

Morphology:

Ah – 0–3 cm, humus horizon, silt loam, very dark grayish brown (10YR 3/2), slightly moist, medium moderate granular-subangular blocky structure, very fine and common roots, clear and smooth boundary;

Bw – 3–20 cm, *cambic* horizon, silt loam, brown (10YR 4/6), moist, medium weak-moderate subangular blocky structure, fine common roots, gradual and smooth boundary;

BC – 20–45 cm, silt loam, dark yellowish brown (10YR 4/7), fresh, medium very weak subangular blocky structure, medium very few roots, gradual and wavy boundary;

C1 – 45–70 cm, silt loam, light yellowish brown (10YR 5/6), dry, rock structure, very few roots, illuvial lamellae, gradual and smooth boundary;

C2 – 70–105 cm, silt loam, light yellowish brown (10YR 6/4), dry, rock structure, gradual and smooth boundary;

C3 – 105–(150) cm, silt loam, light yellowish brown (10YR 6/4) dry, rock structure.

Table 1. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
Ah	0–3	1.8	1.6	3.9	8.5	12	12.6	28.6	22.4	5.9	4.5	SiL
Bw	3–20	0.5	1.4	3.1	5.6	12.6	4.7	18.1	25.9	13.9	14.7	SiL
BC	20–45	1.7	2.2	2.5	4	11.5	7.7	19.7	24.2	11.9	16.3	SiL
C1	45–70	1.5	1.7	2.2	3.3	8.8	9.4	20.6	23.1	11.7	19.2	SiL
C2	70–105	0.6	0.9	1.2	2.1	7.4	8.2	22.8	25.7	12.7	19.0	SiL
C3	105–(150)	0.4	1.1	1.9	4.4	9.1	11.9	23.0	21.7	9.3	17.6	SiL

Table 2. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [g·kg^{-1}]	Nt [g·kg^{-1}]	C/N	pH		$CaCO_3$ [g·kg^{-1}]
					H_2O	KCl	
Ah	0–3	29.4	-	-	5.4	4.7	3.9
Bw	3–20	12.2	-	-	4.2	3.8	4.5
BC	20–45	4.0	-	-	4.7	3.8	5.8
C1	45–70	1.6	-	-	4.9	3.8	5.0
C2	70–105	2.3	-	-	5.0	3.9	3.2
C3	105–(150)	4.4	-	-	4.9	3.7	7.2

Profile 2 – Episkeletic **Umbrisol** (Pantosiltic, Siltinovic)
Localization: Niche, medium slope - inclination 13°, grass vegetation, slope 417 m a.s.l.
N 48°29'45.93 **E** 21°23'16.98"

Morphology:

Ah – 0–10 cm, *umbric horizon*, silt loam, very dark brown, dark grayish brown (10YR 2/2, 10YR 4/2), slightly moist, medium weak subangular blocky structure, skeletal parts (30%), very fine and common roots, clear and smooth boundary;

AC – 10–40 cm, *umbric horizon*, silt loam, very dark brown (10YR 2/2), slightly moist, medium weak subangular blocky structure, skeletal parts (50%), few fine roots, gradual and smooth boundary;

CR – 40–(80) cm, silt loam, dark brown (10YR 3/3), dry, few large roots, skeletal parts (70%), rock structure.

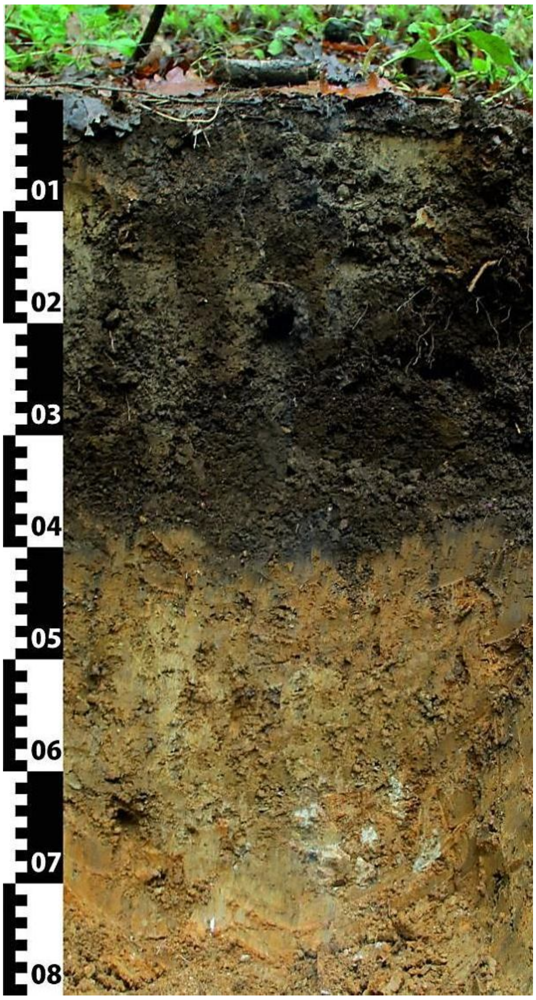
Table 3. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
Ah	0–10	0.7	0.5	1.5	4.5	9.8	8.3	26.1	28.4	8.9	12.0	SiL
AC	10–40	0.1	0.5	1.3	4	9.8	7.2	22.3	27.4	12.2	15.3	SiL
CR	40–(80)	7.1	3.6	2.4	2.1	8.8	8	19	22.7	11.8	21.6	SiL

Table 4. Chemical and physicochemical properties

Horizon	Depth [cm]	OC [$g \cdot kg^{-1}$]	Nt [$g \cdot kg^{-1}$]	C/N	pH		$CaCO_3$ [$g \cdot kg^{-1}$]
					H_2O	KCl	
Ah	0–10	32.4	-	-	4.9	3.7	5.3
AC	10–40	10.0	-	-	5.4	3.9	5.0
CR	40–(80)	0.0	-	-	6.3	4.6	6.1

Profile 3 – Amphistagnic Amphiluvic **Umbrisol** (Episiltic, Amphiclayic, Endoloamic, Siltinovic, Transportic)
Localization: Niche, medium slope - inclination 13°, deciduous forest vegetation, slope 406 m a.s.l.
N 48°29'37.58" **E** 21°23'21.46"



Morphology:

Ahu – 0–20 cm, *umbric* horizon, silt loam, very dark grayish brown (10YR 3/2), slightly moist, medium moderate subangular blocky structure, very fine and common roots, redeposited soil material, gradual and smooth boundary;

Ahb – 20–40 cm, *umbric* horizon, silt loam, very dark grayish brown (10YR 3/2), slightly moist, fine moderate subangular blocky and granular structure, fine very few roots, clear and smooth boundary;

Btg – 40–60 cm, *argic* horizon, silty clay, dark yellowish brown (10YR 4/4), slightly moist, medium strong subangular - angular blocky structure, *stagnic* pattern (10YR 4/3; 7.5Y 4/6), cutans, fine and medium very few roots, gradual and smooth boundary;

BCg – 60–(75) cm, silty clay loam, yellowish brown (10YR 5/8), slightly moist, medium weak subangular blocky structure, *stagnic* pattern (10YR 4/3; 7.5Y 4/6), few small skeletal parts, rock fragments.

Table 5. Texture

Horizon	Depth [cm]	Percentage share of fractions, size of fractions in mm										Textural class
		> 2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	< 0.002	
Ahu	0–20	0.9	0.1	0.5	2.4	8.4	5.2	21.3	29.8	10.3	22.0	SiL
Ahb	20–40	0.1	0.4	0.5	2.3	9.8	5.8	23.9	29.5	10.4	17.4	SiL
Btg	40–60	0.1	0.1	0.4	2.3	10	3.2	12.2	19.7	9.3	42.8	SiC
BCg	60–75	0.3	0.3	0.3	2.4	9.5	6.1	13.5	18.6	9.3	39.8	SiCL

Table 6. Chemical and physicochemical properties

Horizon	Depth [cm]	OC $[g\cdot kg^{-1}]$	Nt $[g\cdot kg^{-1}]$	C/N	pH		$CaCO_3$ $[g\cdot kg^{-1}]$
					H_2O	KCl	
Ahu	0–20	24.1	-	-	5.0	3.8	5.9
Ahb	20–40	26.1	-	-	4.9	3.8	5.3
Btg	40–60	4.4	-	-	5.4	3.6	4.9
BCg	60–75	4.7	-	-	5.8	4.0	4.1

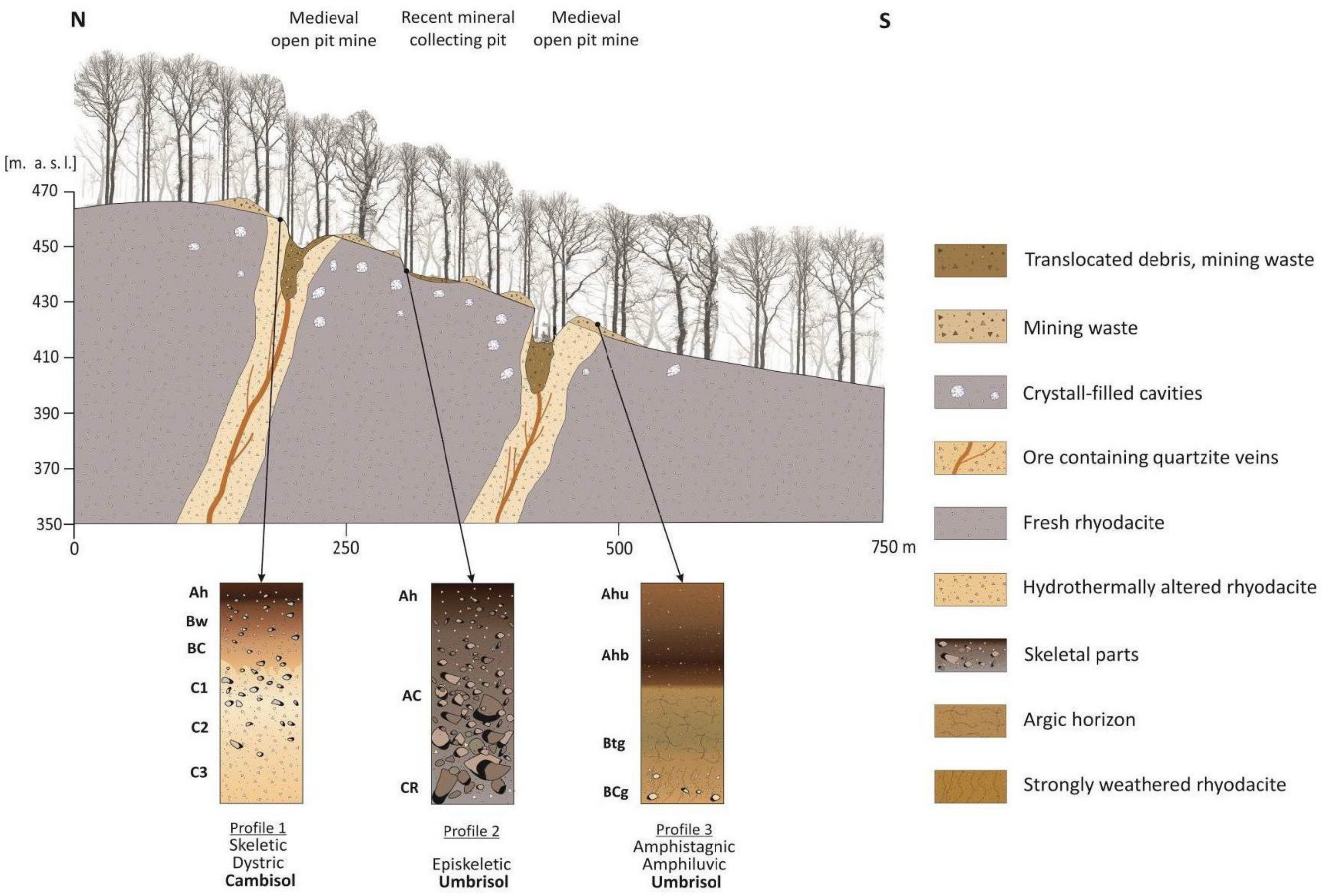


Fig. 2. Sequence of soils of the abandoned gold and silver mining area on volcanic-hydrothermal rocks

Land use

The ridges and southern slopes of Sinta-tető are covered by a typical mixed oak forest, *Quercetum petraeae-cerris*, dominated by sessile oak (*Quercus petraea*). The area is part of the Zempén Landscape Protection Area and is currently managed by forest administration. In the Middle Ages and the early New Age, the region was heavily transformed by the mining activity; spoil heaps and mining waste deposits indicate the intensity of this land use. At the end of the 19th century at the latest, all mining activities were discontinued here and the spontaneous post-mining vegetation development has started. The forests covering this area are the result of at least 150–200 years of secondary succession and nowadays it is difficult to distinguish them from natural ones.

Climate

The study area belongs to the Northern Hungarian Mid-Mountains. According to Kottek et al. (2006) the region is located in the humid zone with warm summer. The average annual temperature is 8°C. The average temperature of the coldest month (January) is -4.5 °C, while the warmest month is July (19.5 °C. The average annual precipitation is about 700 mm. The February is the driest (26 mm), while the highest precipitation is recorded in June (80 mm).

Soil genesis and systematic position

Profile 1 was classified as **Cambisol** (IUSS Working Group WRB, 2015), characterized by the presence of the *cambic* horizon starting at the surface and reaching a depth of 20 cm. Skeletal parts such as rock debris and rock fragments were present in >40%, therefore the ***Skeletic*** principal qualifier was applied, while low pH (3.8 in KCl solution) indicates its low base saturation, hence the ***Dystric*** qualifier was also added. The texture of fine earth is found to be silty loam in all horizons, which is indicated by the ***Pantosiltic*** supplementary qualifier. The shallow humus-rich layer and its relative low OC content is expressed by the ***Ochric*** supplementary qualifier.

Profile 2 was classified as **Umbrisol** (IUSS Working Group WRB, 2015), because the Ah and AC horizons have a dark colour (10YR 2/2 moist), a well-developed structure and a sufficiently high organic carbon content, but the base saturation is presumably low due to low pH (3.7). These first two horizons together exceed the minimum thickness criteria for the *umbric* horizon. The skeletal parts between the soil surface and the depth of 100 cm account for >40% of the soil volume. Therefore, the ***Skeletic*** principal qualifier was added to indicate it with the ***Epi-*** specifier, since this characteristic appears already in the topsoil, between the soil surface and the depth of 50 cm. The base rock is different from the first location, but the chemical characteristics of its weathering products are similarly acidic, resulting in low pH and presumbly low base saturation. The texture of the soil in fine earth is entirely silty loam, therefore the ***Pantosiltic*** supplementary qualifier was added.

Profile 3 was similarly to Profile 2 defined as **Umbrisol**, having a 40 cm thick, well-structured, organic rich, dark coloured but strongly acidic surface horizon, which meets the criteria of the *umbric* horizon. Directly below the umbric horizon, the *argic* diagnostic horizon could be identified, which also has a *stagnic colour pattern* with rusty brown and greyish distinct patches. Both characteristics appear at a depth from 40 to 60 cm, therefore the ***Amphiluvic*** and ***Amphistagnic*** qualifiers were added. The texture is siltic in the *umbric* horizon, which was described with the ***Episiltic*** supplementary qualifier, clayic in the *argic* horizon, hence the ***Amphiclayic*** qualifier, and loamic below the *argic* horizon, which is expressed by the ***Endolamic*** qualifier. The surface horizon is still recognizable as redeposited soil material, in which parts of various colours and structures are not completely mixed. For this new surface layer, the supplementary qualifier ***Novic*** was added and its texture class is indicated by the ***Silty***- specifier. This together with the buried surface horizon still meets the criteria of the *umbric* horizon, but its anthropogenic modified thickness and position should be indicated by the ***Transportic*** supplementary qualifier.

Soil sequence

Mining areas are usually characterized by **Technosols** due to the presence of mining waste, which is classified as artefacts when the material brought to the surface by mining was previously not affected by surface processes and significantly differs from its environment. In our case, mining was present in the preindustrial time and only shallow layers of mining waste could be found on the surface. Furthermore, in the period since the cessation of mining, the debris was subjected to weathering processes and the mining waste is excavated from the direct vicinity of the surface. Therefore, the old mining waste in the studied profiles could not be defined as *artefacts*, but as *transportic*, and *novic* material above the original soil horizons.

Profile 1 is located on the edge of an abandoned medieval open mine pit and it represents soil developed on weathered, hydrothermally altered rhyodacite, which is not covered by later, anthropogenically translocated mining waste or debris. The surface further away from the pit is slightly elevated by the redeposited material excavated during the mining, but nearly the original soil surface was visible in profile 1. Therefore, in the case of profile 1, anthropogenic influences are not recognizable. Profile 2 is located at a shallow pit, excavated by hobby-mineralogists in fresh, dark grey rhyodacite rock, containing crystal-filled cavities. The redeposited rock debris and soil material covering the original soil surface is <20 cm and not continuous, therefore only the Novic supplementary qualifier applies, with the addition of the texture class of fine earth of this reworked material: ***Siltinovic***. At profile 3, the surface is covered by 20 cm thick redeposited soil material, which together with the original soil topsoil horizon meets the minimum thickness criterium for Umbric, which means that it contains part of the *umbric* horizon, but it is at the same time ***Transportic*** and ***Siltinovic***.

The soil sequence shows typical soils developed on weathered acidic volcanic rocks, containing a relatively large proportion of skeletal parts. Anthropogenic influences are still recognizable, but in the described soils the taxonomy reflects them only at the level of supplementary qualifiers.

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References

Ilkey-Perlaki, E., 1978. Explanation for geological maps of the Tokaj-mountains, 1:25 000 series, Geological Institute of Hungary, Budapest: 1–55. (in Hungarian)

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. FAO, Rome.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. 2006. World Map of Köppen-Geiger Climate Classification updated. Meteorol. Z., 15: 259–263.

Molnár, F., Zelenka, T., Pécskay, Z. 2009. Geology, styles of mineralization and spatial-temporal characteristics of the hydrothermal system in the low sulphidation type epithermal gold-silver deposit at Telkibánya. Publ. Univ. Miskolc, Ser. A. Min. 78: 45–71.

Pécsi, M., 1995. Loess stratigraphy and quaternary climatic change – Loess in Form 3, Geographical Research Institute, Hungarian Academy of Science: 23–30.

Zelenka, T., Gyarmati, P., Kiss, J. 2012. Paleovolcanic reconstruction in the Tokaj Mountains. Central Europaean Geology 55 (1): 49–84.

Zelenka, T., Horváth, J. 2009. Characteristic of the Telibánya veins. Publ. Univ. Miskolc. Ser. A. Min. 78: 71–97.