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ORIGINAL ARTICLE

Anthropic Vulnerability of a Hydrothermal Mineral Deposit and Related Mining Heritage, a Case Study from a Medieval Gold-Silver Mining Area, Telkibánya, Hungary

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Abstract

The movable geoheritage elements (minerals, fossils, rocks) are important part of geodiversity. Their anthropic vulnerability includes collection by geo-amateurs and professionals which has become a very popular activity in the last decades. The in situ protection of such geoheritage elements preserves their authenticity and integrity, but needs detailed inventory and assessment providing recommendation for geoconservation. The aim of this study is to investigate a medieval mining site of the Carpathians (Telkibánya, Hungary) where recent anthropic vulnerability related to mineral collecting. Earlier works emphasized the scientific, aesthetic, and geo-educational potential of the mineral association and mining heritage of the study area. Our field survey gives a review of medieval mining works and the current state of the surviving infrastructure identifies the major areas of mineral collecting disturbances and the integrity of the main and additional geological elements. Based on the degradation risk assessment, further conservation management initiatives are proposed by open collecting outcrops (exposure sites) and declared protection with controlled collecting (finite sites).

Keywords Vulnerability · Mining heritage · Mineral collecting · Geoconservation · Geoethics

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Introduction

There are many anthropic activities that stress geological sites and geoheritage (Fuertes-Gutiérrez et al. 2016; García-Ortiz et al. 2014). Two major triggers are public use (mining, quarrying, infrastructure construction) and anthropic vulnerability (recreational uses, collecting, vandalism). Rocks, minerals, and fossils are important assets of geotourism. Their anthropic vulnerability includes collection by geo-amateurs and professionals which has become a very popular activity in the last decades (Johnson and Suneson 1996; Natural England 2012). The continuous increase in the number of mineral collectors worldwide promotes national and international trades (e.g. Morocco fossils (Gutiérrez-Marco and García-Bellido 2022); Brazilian gemstones (de Brito Barreto and Bretas Bittar 2010)).

Surface and underground excavation possibilities are limited in most cases by state laws and other nature conservation regulations (Prosser 2008; Körmendy 2010; Witt 2016; Kuhn et al. 2022a, b). Conservation allows the scientific and educational use of the resource, whereas preservation implies that the resource is completely protected from any form of further depletion (Fuertes-Gutiérrez et al. 2016). This concept brings new challenges and tasks in environmental management with identification of the threats affecting geoheritage as well as the assessment of risk of degradation (Fuertes-Gutierrez and Fernandez-Martinez 2012; Tavares et al. 2020; do Nascimento et al. 2021). The paleontological heritage is receiving more attention regarding both case studies and geoethics (DeMiguel et al. 2021; Kuhn et al. 2022a), while mineral deposits are less investigated.

Mitigating the damage made during collecting (rockhounding), as an identified threat, needs enhanced geological conservation measures (Prosser et al. 2006). The adaptation of a responsible approach made the resources available for future generations. In England, the site management identifies the pressure from collecting, and the endangered sites are grouped into three main categories: exposure, integrity, and finite. The open or controlled collecting initiatives define categories of site management in terms of sustainability (Prosser et al. 2006; Natural England 2012, Crofts et al. 2020). In Hungary, Act LIII of 1996 specifies that minerals, other geological remains, and their significant deposits should be declared protected (Körmendy 2010; Szepesi et al. 2020, sup.) but protection at a level of mineral species is an unsolvable task. After private and educational collecting, the Hungarian amateur activities started in the 1970s but the growth in numbers of geo-amateur and professional collectors occurred in the 1990s and 2000s. The periodical (Geóda journal, minerofil.hu/geod.php) and national collector's website (geomania.hu) gather the basic descriptions of mineral occurrences where the hydrothermal deposits of Tokaj Mountains are one of the most frequent occurrences (1/6 of database, Fig. 1). The amount of Hungarian minerals (in natural or polished form) coming to the market is significant and connected to uncontrolled professionals (1% of the community, penzcentrum.hu). Despite this, Hungarian site– or occurrence–based initiatives for management have not been established.

Based on the above, the delineated study area is a medieval mining site in Hungary with collecting-based degradation. The exploited hydrothermal veins developed in Miocene altered volcanic rocks (andesite, rhyolite, dacite) with a low sulphidation type mineralization (sulphides, sulphates, quartz varieties). The selection of the area is due to following reasons: (a) high geoheritage value of medieval mining areas (Szepesi et al. 2017, 2020; Ésik et al. 2019; Ésik 2022) including natural (mineralogical paragenesis, Szakáll and Weiszburg 1994; Szakáll 2009) and anthropogenic (mining heritage, Zelenka and Horváth 2009) geodiversity elements; (b) the site is important in regional geotourism which is emphasized by an established nature trail and educational resource center (Hartai and Németh 2012); (c) the frequency of regional mineral collecting as highlighted by 20 described sites from the mineralization area (geomania.hu).

Our research with the support and cooperation of Aggtelek National Park Directorate focuses on the detailed field survey of the medieval mining area including the historical review of medieval works and field survey of the survived surface infrastructure. The study characterizes the state of the medieval surface and underground mining infrastructure, delineates the various mining subregions, identifies mineral collecting disturbances, and proposes further conservation management.

Mineral and Fossil Collecting

The collecting of rocks and minerals dates back to prehistoric times. For tool making such as blades and arrowheads, hard stones (e.g. volcanic rocks), volcanic glass, and quartzite were used (Biró 1984, 2002; Mester and Faragó 2016). Archeological studies reported many minerals with unusual shape as jewelries in graves. The first written descriptions of mineral and rock collecting, including usage and the technique of processing, date back to Ancient Egypt. Manufacturing steadily expanded with the extraction of various industrial minerals through centuries. Rock, mineral, and fossil collecting as a hobby became more common with the development of earth (natural) sciences (seventeenth–eighteenth century). Amateur collecting is also referred to as rockhounding in the USA and Canada (Johnson and Suneson 1996). Mineralogical societies (American Federation

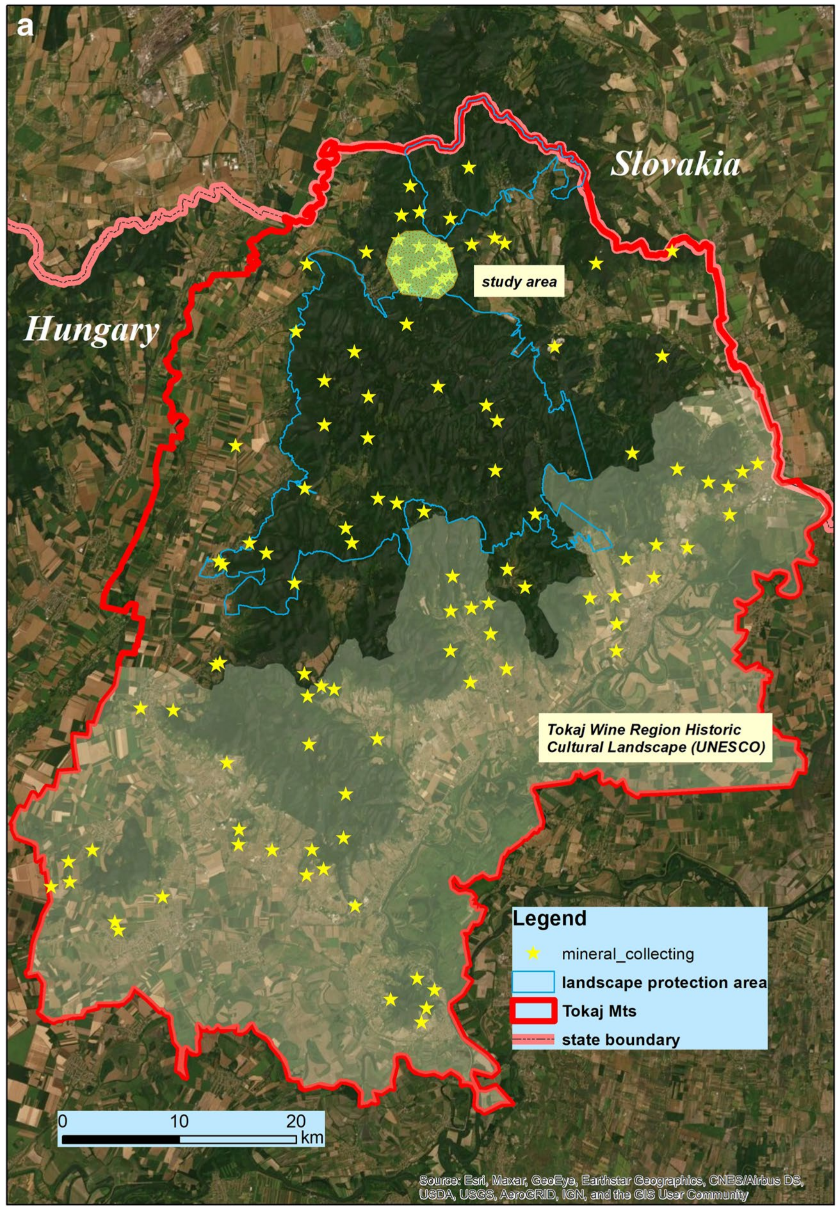

Fig. 1 **a** Position of Tokaj Mts and the study area; yellow stars indicate mineral collecting sites (details see geomania.hu). **b** Mining sites in Central Europe

of Mineral Societies, Hungarian Friends of Minerals and others) organize materials for professionals (geologists, mineralogists) and amateurs (e.g. Geoda periodical, Hungary). Today, the international industry includes gemstones, minerals, and fossils with specialized stores, festivals, and mineral shows. The fossil trade of Paleozoic material from southern Morocco was estimated by some North American media to reach about US$ 40 million a year, and it supplies fossil shows and shops all over the world.

In the Carpathian region, there were many significant mining sites in European scale (Hungary: Telkibánya, Rudabánya, Slovakia: Banska Bystrica, Banska Stiavnica, Fig. 1b). In the nineteenth century, public collections were established in schools and museums but the largest collections continued to be held by landowners, pharmacists, doctors, mining officers, teachers, and lawyers interested in natural sciences. In the first half of the twentieth century, the territorial changes caused a great disruption in mineral collection in Hungary, as the most renowned mining sites were moved outside the borders. The number of collectors fell, and the development of school and museum collections came to a standstill. Despite this, some great private collections have been created. The devastation of World War II and following decades completely wiped out Hungarian collecting. A slow change came in the 1960s. After individuals re-started rockhounding, the organized collecting movement began in the 1970s. Mineral collector groups were established in Budapest and the countryside. As soon as mineral collecting attracted masses of people, the first markets and festivals appeared, where the collected material could be

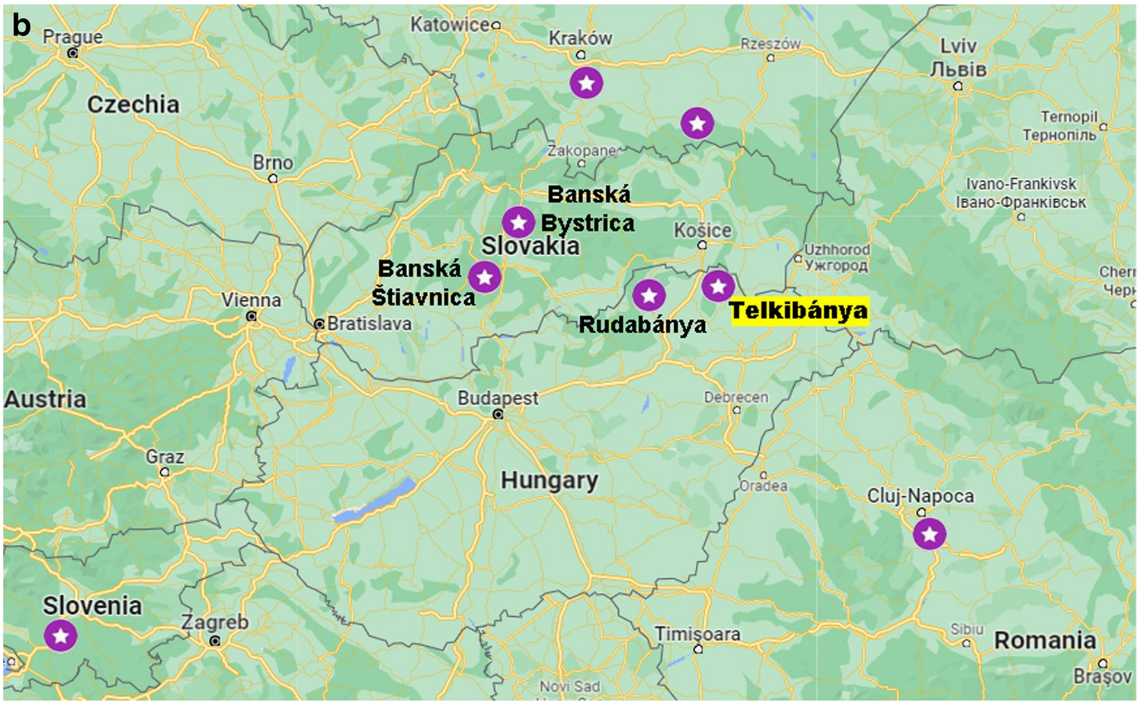

Fig. 1 (continued)

exchanged, sold, or bought (e.g. International Show, Miskolc, asvanyfesztival.hu). Eventually, the first independent organization was founded (Hungarian Friends of Minerals) coordinating collectors and specialist groups. Today, there are about 3000 people in Hungary who regularly collect minerals as amateurs (penzcentrum.hu). The continuous increase in the number of mineral collectors resulted in the establishment of a national, site-based compilation in 2007 (geomania.hu). The listed sites from the Tokaj Mts (1/6 of the national database) are shown in Fig. 1. Mineral collectors appeared here in the 1980s and mainly focused on minerals of the widespread hydrothermal deposits.

Geographical Settings and Mining History

The Telkibánya Medieval Gold-Silver mining took place in Tokaj Mountains (TM) in the northeastern part of Hungary. The TM is a medium-height volcanic mountain along the Hungarian-Slovakian border, covering approximately 1100 km^2 (Szepesi et al. 2017). The northern part, around the study site, is a mountainous area with forestry and historical mining industry (clays, perlite, building stones). While the southern part is the Tokaj Wine Region Historic Cultural Landscape (Fig. 1), a hilly, agricultural area was declared a UNESCO World Heritage Site in 2002 (Szepesi et al. 2017). The mountain is mainly built up by Miocene (15–9.4 Ma; Pécskay et al. 2006) volcanic (andesite, dacite, rhyolite) and volcaniclastic (rhyolitic, dacitic lapilli tuffs) rocks. Regionally, the Miocene volcanism is associated with widespread hydrothermal alteration (Pécskay and Molnár 2002; Molnár et al. 2009). The major alteration zonation included silicification, potassic, and argillic style in relation to different magmatic centers (calderas, subvolcanic bodies). The Telkibánya Au–Ag deposits developed in an andesitic volcanic center (13.1–12.4 Ma; Pécskay and Molnár 2002) surrounded by rhyolite-rhyodacite lava domes (Molnár et al. 2009; Szepesi et al. 2019). Subordinate volcaniclastic and sedimentary units settled down on the margins (Fig. 2).

The study area covers 4 municipalities (Fig. 2) around the central Kánya (615 m a.s.l.) and Gyepű hills (530 m a.s.l.). From nature conservation point of view, the mountain is managed by Aggtelek National Park Directorate. Unfortunately, the Zemplén Landscape Protection Area covers only the Király Hill in the study area (Fig. 1a) which is also declared as a Natura 2000 protection site (natura2000.eea.europa.eu).

Historical mining started in the tenth century (Benke 2009). The first written documentation dating back to the fourteenth century when the reserves were estimated for the Hungarian Royal Court. The mining, along with the other mining towns, flourished at this time of Hungarian Kingdom. The gold abundance from the American continent (sixteen–seventeenth century) caused market relapse and after several declines, the mining activity ceased in the nineteenth century. The remaining infrastructure includes larger pit fields on the surface following the quartz veins, underground adits (in valleys and on slopes, 30 pcs), and deep air ventilating shafts. Silicified conglomerate was quarried for grinding millstones (Fig. 3a, Ésik et al. 2019). The history and tools of mining are on display in Telkibánya

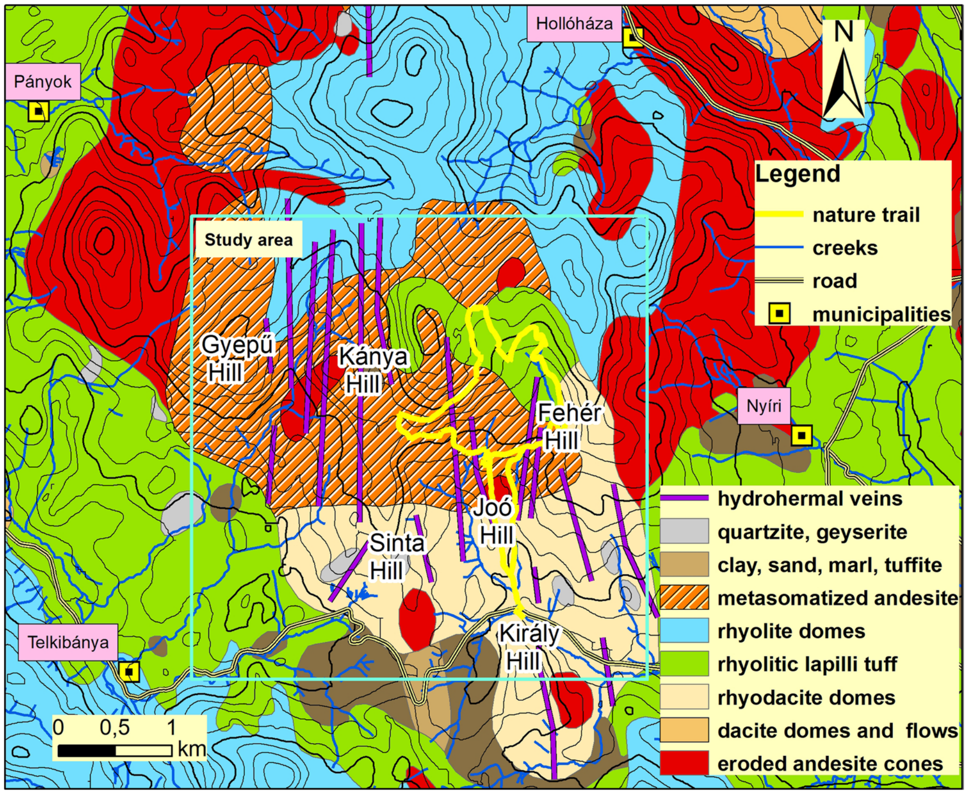

Fig. 2 Simplified geological maps of the study area with the major hydrothermal veins (based on 1:25 000 geological maps)

Ore and Mineral Mining Museum (Fig. 3), founded in 1970 in the building of the first porcelain factory of Hungary. Besides presenting the mining and porcelain production relics (Fig. 3b), it is also an exhibition site of the mountain and Telkibánya minerals.

The Mineral Association

Telkibánya is one of the best explored hydrothermal mineralization sites in the Carpathian Basin. In addition to the documentation of raw material exploration (Scherf 1961; Horváth and Zelenka 1997), thematic geological-mineralogical volumes have been published in recent decades (Székyné Fux 1970; Szakáll and Weiszburg 1994; Németh and Hartai 2009). Epithermal, low sulphidation type mineralization is hosted by a thick (700 m) volcanic-subvolcanic andesite-dacite complex which is partially covered by rhyolite tuff and non-volcanic conglomerate. The surrounding rhyodacite-rhyolite domes were also altered. The vertical-subvertical veins at the mineralization area striking N-S are subparallel to major faults. The length of the major veins is approximately 3 km (Fig. 2) while their width varies between 0.1 and 1 m, and they are commonly surrounded by silicified wall rock breccias (Horváth and Zelenka 1997; Molnár et al. 2009). The K-metasomatic (adularia-sericite) alteration caused an elevated K_2O content (over 8%) in the wall rock. At a certain depth, propylitic alteration halo and kaolinite-alunite assemblages are also identified. The wall rock alteration occurred at 180–250 °C ranging between 200 and 500 m paleodepth but affecting the rhyolite-rhyodacite lava domes, lapilli tuff, and conglomerate (Molnár et al. 2009). Thermal and paleodepth zonation has delineated the central (Kánya, Gyepű Hills) and peripheral areas (Fehér, Sinta Hills) of ore mineralization. The number of the identified minerals of the Telkibánya ore deposits is over 60 (Szakáll 2009).

The common species in the mineral paragenesis are quartz varieties (apophysis, smoky, amethyst, chalcedony), sulphides, sulphates, and other small Au–Ag minerals (native gold, acanthite). The major target of mineral collecting is the vein outcrops where euhedral quartz crystals developed in lithophysa holes (geode, Fig. 4c–e) of rhyolite, rhyodacite, and vugs of the brecciated zones. The euhedral crystals (1–8 cm, Fig. 4a) have well-developed prism and rhombohedral faces, while the vein filling quartz has anhedral-subhedral habit (Molnár and Szakáll 1994). Opal (e.g. rhyolite lithophysae, Gyarmati et al. 1986) and chalcedony also occur commonly. The eponymous silicate mineral (adularia) of the hydrothermal alteration (adularia-sericite) is also very common, which developed as displacement of the rock forming plagioclase or individual crystals in the vugs. Bladed calcite pseudomorphs replaced by quartz, characteristic at medium levels of the low sulphidation type epithermal alterations, and are also common in the veins

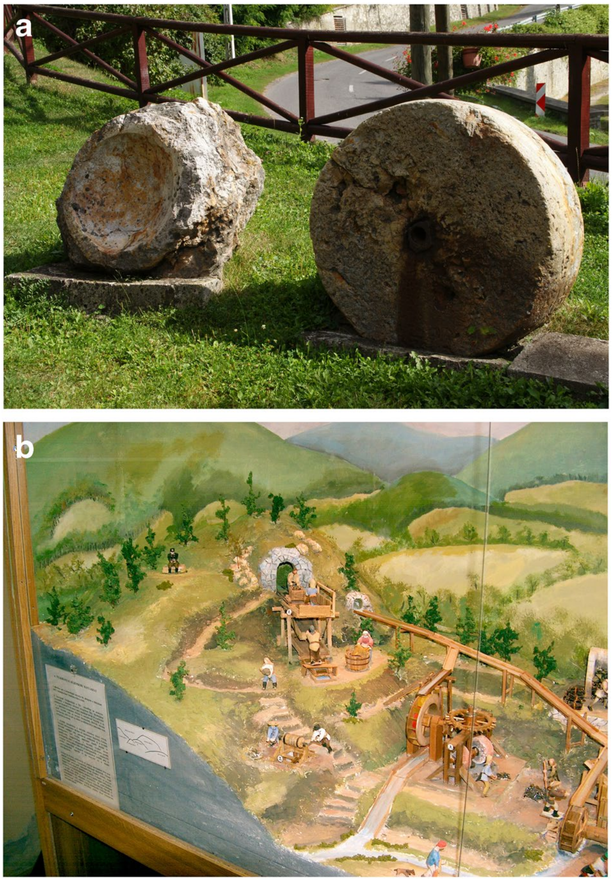

Fig. 3 **a** Grinding millstones in the garden of Ore and Mining Museum. **b** Model of medieval mining work (grinding and smelting) in the museum

(Fig. 4g). The sulphides are subordinate minerals in the ore veins. Beside the common pyrite, sphalerite, galena, marcasite was also identified. The Ag precipitation is associated with acanthite and other Ag bearing sulfosalts (Molnár et al. 2009). Native gold appears as fine inclusions in quartz and pyrite (100–150 µm), or as individual small grains and fibrous masses. The overall enrichment varied between 7 and 20 ppm for Au, and 100 and 800 ppm for Ag. Considering sulphates, jarosite, gypsum, and alunite are more frequent. Barite crystals (up to cm) with tabular habit appear in rhyolite lithophysae of Fehér Hill (Fig. 4f). Carbonates (e.g. ankerite, aragonite, dolomite) and halogenides (e.g. chlorargyrite AgCl, HgAgI, PbCl) further enrich the paragenesis.

Methods

The study area covers the medieval mining district with more than 20 km^2 (Figs. 1, 2, and 6). The survey of the individual mining sites started in 2015 under the coordination of Aggtelek National Park Directorate with geoconservation purposes. The central mining area (Kánya, Sinta, Joó hills, Fig. 6a–c) was mapped in the course of an extensive field campaign in 2018 at a scale of 1:1000. Based on literature review, we defined 5 major object types for mapping (Table 1). The survey recorded medieval mineral excavation sites (pitholes, adits, air shafts) and their mining waste and the recent mineral collecting disturbances. Beside GPS coordinates, simple object parameters were recorded (pits, diameter, depth, adit length, height of the dump material, Table 1). For other two sites (Gyepű and Király hills – Telkibánya), geoconservation-based description was conducted including site management and conservation issues. Soil surveys were carried out to monitor the depth and temporal variation of mineral collecting disturbances on Sinta Hill. The soil profiles were described according to the WRB system (IUSS Working Group WRB. 2015; Novák and Szepesi 2018).

Degradation risk as an important aspect of geosite assessment has been evaluated by Reynard et al. (2007), de Lima et al. (2010), and Fassoulas et al. (2012). Recently published method of Brilha (2016) used a weighted process with five criteria; therefore, we have recorded them accordingly (Table 2) for ranking the degradation risk of the mining subregions (Table 5).

Results

The geoconservation site mapping surveyed 6 major medieval pit fields (Kánya, Sinta, Fehér, Joó, Veresvíz, Gyepű) in the study area with an extent of 0.04–0.9km^2 (Fig. 6, Table 3). The Király Hill conservation area is connected from south (Figs. 2 and 6b) but here sporadic mining heritage was documented (Horváth and Zelenka 1997). The surveyed area reached 20 km^2 with object number over 2000 (Table 3). The largest density was identified at Kánya Hill (Fig. 6a), which contains the half of the surveyed object number. The mining heritage classified as surface (pit, air ventilation/exploitation shafts) and underground objects (draining/exploration adits; Fig. 5 and Tables 1 and 3).

Surface Mining Infrastructure

The surface mining objects included pits and the opening of the transport/air ventilation shafts (Fig. 5, Table 3). The pits were primarily vertical exploitation shafts (6–8 m, Fig. 7a), but after abandonment, they collapsed and filled (Fig. 7b). Their size varied as a function of hydrothermal vein width and the amount of extracted material. The largest reached a diameter of 10 m and a depth of 8 m (Joó Hill, Fig. 7a). They averaged 5 m in diameter and 0.5–2 m in depth (Fig. 7b) depending on the post-mining fill (up to 80% of the original volume). The pits are arranged to

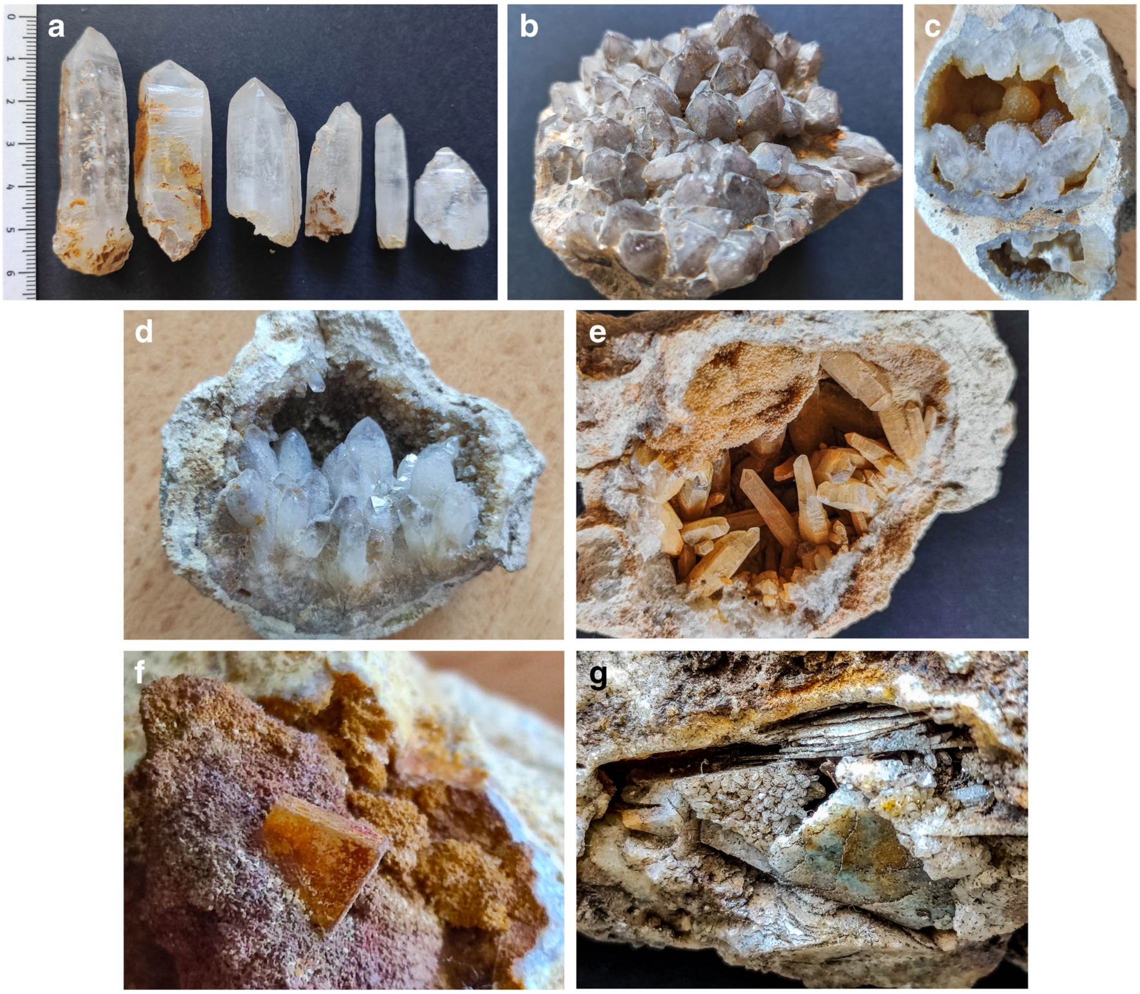

Fig. 4 Minerals of Telkibánya medieval gold-silver mining area. **a** Large apophysis quartz crystals, Sinta Hill; **b** smoky quartz from a hydrothermal vein, Kánya Hill (width 8 cm); **c–e** rhyolite geodes (Ø 4–5 cm) from Fehér Hill; **f** barite (3 mm) from Fehér Hill rhyolite; **g** quartz pseudomorphs after bladed calcite (2.5 cm), Kánya Hill, Jószerencsét vein. Photos by J. Szepesi

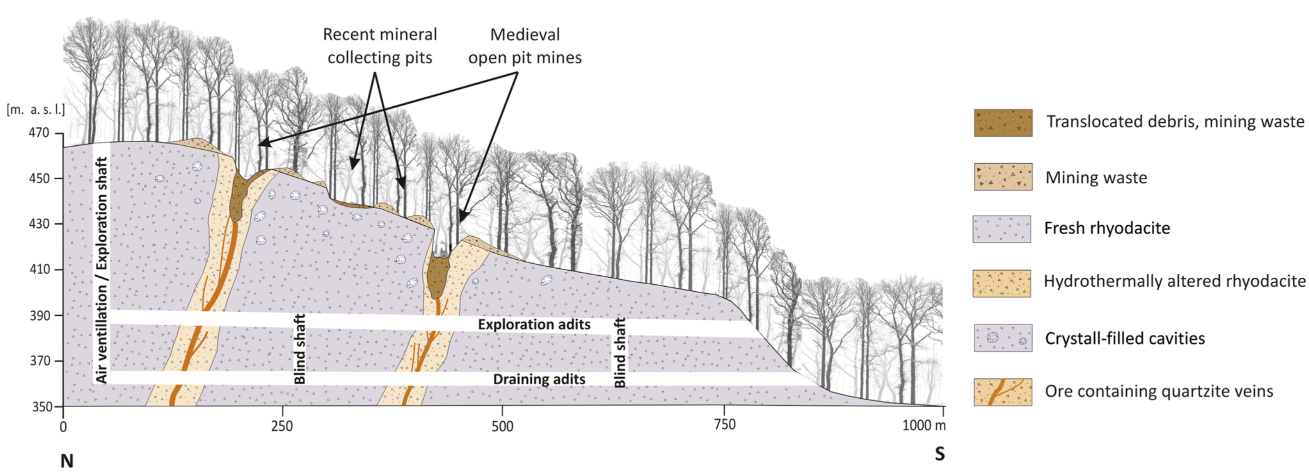

Fig. 5 Structural and exploratory sketch of the Telkibánya medieval gold-silver mining area

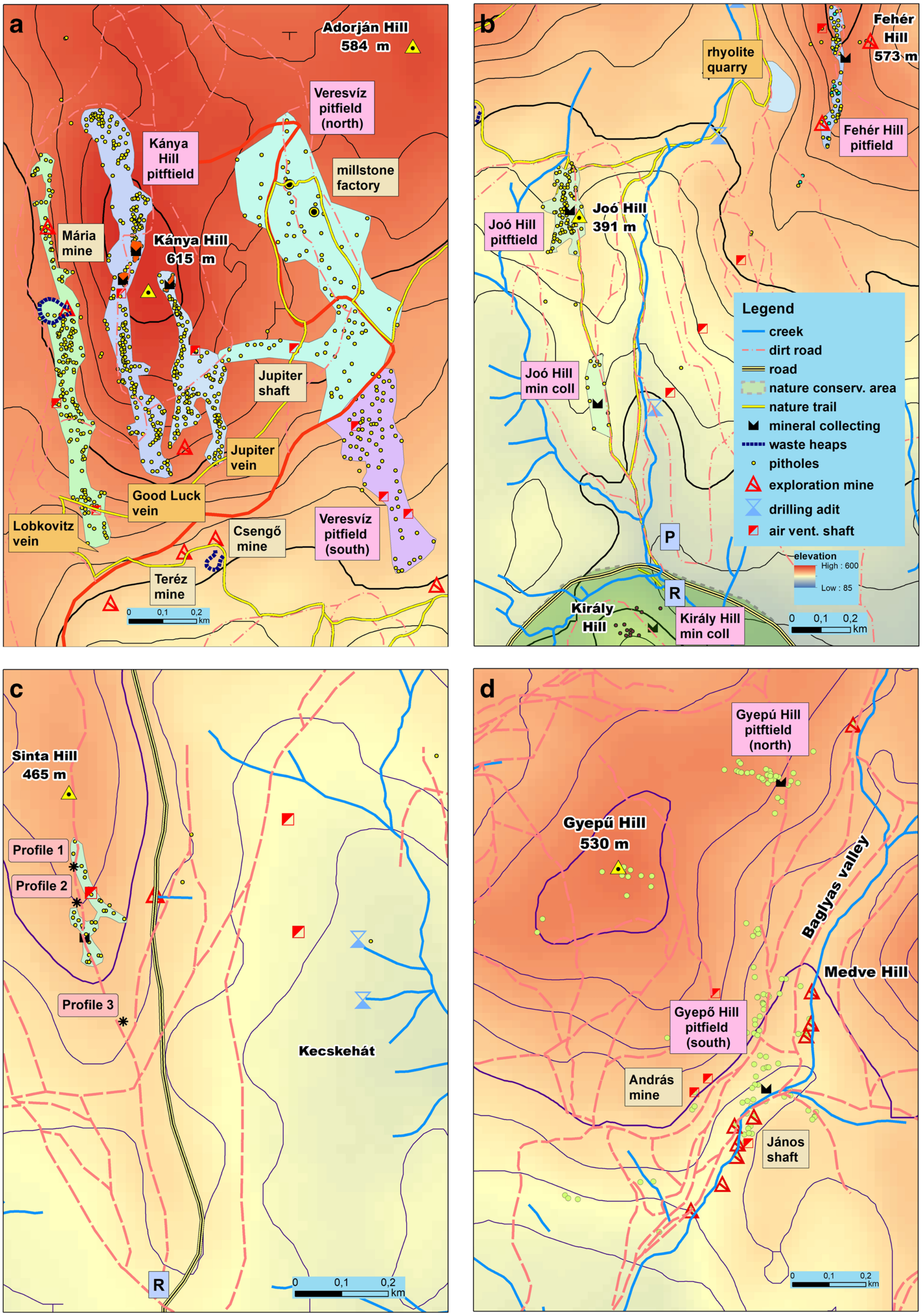

Fig. 6 Field survey of Telkibánya medieval gold-silver mining area highlighting mineral collecting sites. **a** Kánya Hill – Veresvíz pitfield. **b** Fehér, Joó, Király hills pitfields. **c** Sinta and Kecskehát hills. **d** Gyepű Hill – Baglyas Valley pitfield

Table 1 Major object types and surveyed dimensions of the study area; for cross-sectional view, see Fig. 5

	Definition	Dimensions
Pitfield	Circular or oval-shaped conical excavation sites arranged in lines following the ore veins on the surface. Primarily, these were vertical shafts (6–8 m), but after abandonment, they collapsed and were filled. Recently, common depth between 1 and 2 m, largest up to 5–7 m depth, variably filled with post-mining reworking and debris (up to 80%)	Diameter, depth, estimated backfill
Adits	Linear horizontal underground excavations at different levels, the lowest are draining channels (along valley), removing water from the upper zone to work, and there are sections for transport only, usually collapsed opening	Cross section, length, safety condition
Exploratory/air ventilation shafts	Passages for vertical transportation and/or moving fresh air to underground, ventilating depth up to 100 m, surface opening in rock or large pithole (usually collapsed)	Diameter, estimated safety conditions
Mine damp	Material extraction and accumulation that is connected to mining operations and comprises of waste rock and other residue. All surface objects (pits, shafts) have smaller or larger waste tailings	Areal extent, height
Mineral collecting (MC) disturbances	Surface excavation with variable shapes and depths a, debris collecting b, pithole dump reworking b, new MC disturbances c, quarry collecting	Areal extent, depth, biodegradation, safety conditions

Table 2 Weights for the different vulnerability assessment criteria; for details, see Brilha (2016)

Criteria	Weight
A. Deterioration of geological elements	35
B. Proximity to areas/activities with potential to cause degradation	20
C. Legal protection	20
D. Accessibility	15
E. Density of population	10
Total	100

following the veins in linear or diffused pattern and surveyed in all mining sub-areas (Fig. 6). They were most numerous in the central Kánya Hill area (Kánya, Veresvíz pitfield) (200 pits/vein, Fig. 6a), but there was a significant concentration in the vicinity of Baglyas Valley on the eastern side of Gyepű Hill (Fig. 6d). For the other sites, the narrow hydrothermal ridges had a higher density of objects (60–100 pit/vein). The fewest number were recorded in Fehér (60 pit, Fig. 6b) and Sinta hills (< 50, Fig. 6c). The openings of the transport and air ventilation shafts are much larger (> 10 m, Fig. 7c and d). The maintenance of these has required constant ploughing, so that today they are mostly found in a collapsed state (ca 40, Fig. 7c). The largest of these is the collapsed Lipót shaft, with a diameter of 30 m and a depth of more than 10 m. The Lobkovitz shaft (Fig. 7d) in Kánya Hill and the János mine in Gyepű Hill are still open to the surface, with depths of over 100 m.

Underground Mining Infrastructure

The underground infrastructure comprises the mines (adits) driven at different levels (Figs. 5, 6, and 8, Table 3, Horváth and Zelenka 1997). From these, about 20 have been identified during the fieldwork but only two are open to the public. There are a few, hardly accessible partial openings but their conditions and to approach them are dangerous (András mine, Gyepű Hill, Fig. 6d). In the other shafts, only the collapsed openings are reminiscent of former mining operations (Veresvíz adit, Fig. 8e). The Maria mine (at 517 m a.s.l. Figure 8a and b) is the longest restored adit and open to visitors. It reaches the first Lobkovitz vein at 20 m, Jószerencsét vein at 198.4 m, the lower zones of which exploited by the connecting vertical shafts (blind shaft, Figs. 5 and 8b). The third vein was the Jupiter, the exploration shaft opened to the surface in the Veresvíz pitfield. The Teréz adit (410 m a.s.l., Fig. 8c and d) is still an open-accessible cut on the southern side of Kánya Hill, heading the same veins from an opposite, westerly direction (Fig. 6a). An interesting feature is that the wall rock alteration is limited to the vein surroundings here (10 m), proving a spatial (areal + vertical) zonation in the mineralization.

The biggest problem in medieval mining was water; therefore, drainage adits were excavated along the valleys (Figs. 5 and 6), which made it possible to work at higher levels. These all are in a collapsed state (Fig. 8e) but the water run-off reminds us of their original role. The level below the valley floors was not excavated due to technical problems of water pumping.

Fig. 7 Elements of the surface mining infrastructure. **a** A pit in almost original condition (not filled with waste) visible altered wall rock at the bottom, Joó Hill pitfield. **b** The rim of an average sized pit (↓2 m, Ø5m, with mineral collector's reworking (white). **c** Collapsed opening of Lobkovitz exploratory shaft (Kánya Hill) with a larger accumulation of waste rock. **d** Unsafe opening of Lobkovitz air ventilation shaft, the depth is over 100 m

Mining Dump

All of the surface and underground objects had a waste dump (Fig. 4) but the surrounding debris of transport shafts, exploration mines (Fig. 6a), and the smeltering sites was quite larger. They are also commonly found around pitholes; the spreading of the debris usually encircles the pit at 90–180°. The dimensions are proportional to the size of the pits. The debris is stacked in the direction of the slope (Fig. 7c). For smaller pits, this means a height of 2–5 m. However, for larger shafts, the height can be as much as 8–10 m. Larger objects are the flat, steep-sided dumps in front of the mines, which acquired their present size and form during the works of the 1950s and 1960s. The largest of these are the Csengő and Mária mine tailings (30–50 m long, 15 m high, Fig. 6a). Flat-topped objects of former ore processing sites, terminating in steep walls, are also typical in stream valleys. They were surveyed in the 1990s (Horváth and Zelenka 1997). In the study area, they occur in the Joó stream (Fig. 6b) and in the valley of Baglyas creek (Fig. 6d), but are also typical of the surrounding valleys where the higher water flow operated the grinding works.

Mineral Collecting

The surface disturbances are classified as a, debris, b, dump or pit wall reworking, c, new mineral collecting pits, and d, collecting from rhyolite quarry (Tables 1 and 3 and Fig. 9). Primary (not mining related) debris collecting identified at Joó and Király hills affects ca 1 ha area on the slopes. The most intense disturbance is associated with vein dump and pitwall reworking. This type is identified at all pitfields (Fig. 6a–d) but the most intense disturbances affected the top of the Kánya and Sinta hills region following the N-S striking ore veins (Fig. 6a and c). The largest excavations are 50–70 m long, 25–40 m wide, and 0.5–2 m deep (Fig. 9). The excavations haunted the quarzitic waste rock material from the medieval mining (Fig. 7a). The minerals

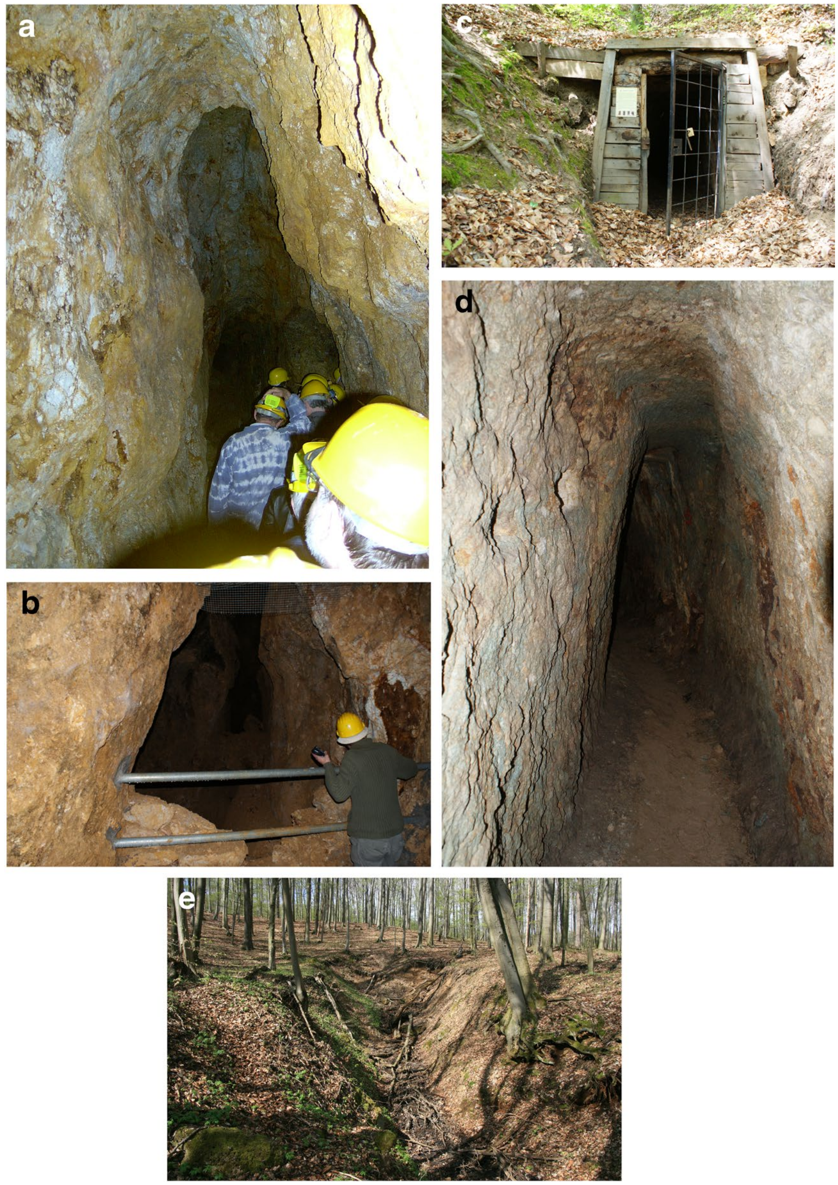

Fig. 8 Underground mines of Kánya Hill. **a** Highly altered wall rock of Mária mine between Lobkovitz and Jószerencsét vein. **b** Blind shaft of Jószerencsét vein. **c** Entrance of Teréz mine. **d** Moderately altered wall rock of Teréz mine. **e** Collapsed entrance of Veresvíz adit

included euhedral quartz crystals (Fig. 4a) and smoky quartz (Fig. 4b), amethyst of the veins. The activity finally resulted in the destruction of the original pit morphology destroying walls and creating large, elongated ditches (Fig. 9a and b). The material is mixed with the reworked soil and forms a secondary fill at the bottom. The recent vegetation is represented by a woody cover (oaks, limes, maples). The root zone of the trees has suffered significant damage. Several have dried out as a result of root cutting. Losing their support, they have fallen to the ground which is a problem for forest owners (Fig. 9b and c).

The third type of mineral collecting is represented by the new mineral collection pits (Fig. 9d). These are mainly associated with the extraction of rhyodacite and related mineralized geodes (Sinta-top, Király Hill). They are also found in the more remote surroundings of the pitfields where no medieval mining was carried out. After the removal of the shallow topsoil (50 cm), large areas (10*10 m, 6*5 m) were excavated or smaller cavities were deepened (1 m <, Fig. 9d). The holes will be backfilled with their own debris after the works are completed, but topsoil degradation is permanent without restoration. The collected vugs are usually filled with quartz, amethyst prismatic crystal, but chalcedony, calcite, and zeolites (Sinta Hill) are also frequent.

The fourth type of collecting is connected to rhyolite quarry debris (Fig. 9e). At Fehér Hill, a mineralized rhyolite wall rock is excavated occasionally and is used by the forestry for road filling. It reveals a heavily fragmented rhyolite lava dome rock with large (up to 10 cm) mineralized lithophysae (Fig. 4c–f). This collecting poses the smallest environmental risk. The minerals include quartz varieties and barite (Fig. 4d), which occur in intermittent zonation.

Table 3 Summary of the fieldwork including major data of the surveyed objects

	Pitfields	Adits	Transport and air ventilation shafts	Mineral collecting (MC)
Kánya Hill, Fig. 6a Largest areal extent ca. 60 ha	Four hydrothermal veins: Lobkovitz, Good Luck, Jupiter August Freud, pitfield length 500–1500 m, width 50–150 m, 600 pits Ø 3–5 m, ↓ 0.5–2 m, large debris accumulation	Exploratory adits southeast: **Teréz**, **Csengő,** Fleischer, west: Tamás, **Mária**, Magdolna	Lobkovitz Ø 10 m, ↓60 m, Jupiter Ø 12 m, ↓5 m (collapsed)	Largest excavation (new and reworking) at the top of Kánya Hill on Jószerencsét (30 × 70, 65 × 40), and Jupiter veins (50 × 25 m), fallen trees, dried root zone, communal waste
Veresvíz, Fig. 6a North 19 ha South 7 ha	Multiple veins, scattered pit location > 150 pits Length 1400 m Width 150–200 m Ø 3–8 m ↓ 0.5–2 m	Draining adit: Veres vízi lower, exploratory adit: Veresvízi upper	Lipót Ø 22 m, ↓6 m, collapsed Jupiter	Pitfield and metallurgical debris reworking
Fehér Hill 2.5 ha Figure 5b	One vein, Length 500 m Width 30–50 m > 50 holes Ø 3–5 m ↓ 0.5–1.5 m	Lower Fehér Hill draining adit, 5 more exploratory mines	4 collapsed holes	Pitfield reworking and Fehér Hill rhyolite quarry
Joó Hill Figure 6b Medieval pitfield: 3 ha Mineral collecting: 2 ha	One vein, Length 350 m Width 50–100 m > 90holes Ø 3–5 m ↓ 0.5–1.5 m, but some large Ø 10 m ↓ 8 m	Exploratory mines Anna, Hosszú árok Vizes and Gusztáv Adolf adit	Smaller collapsed 4	Pitfield reworking Surface silicified debris reworking
Király Hill ha) Figure 6b	No hydrothermal wein, disperse silicification	Only 1 small adit, with ice 'cave'	-	Surface mineral excavation a, Surface debris reworking b, Deeper excavations reaching coherent rock
Sinta Hill, Kecskehát 1.2 ha Figure 6c	One vein, smallest pitfield ~ 40 small pits Ø 3–5 m ↓ 0.5–2 m	Draining adit: Kecskehát, exploratory mines: Koppy, Lobkovitz	Koppy, Kecskehát (collapsed)	Pit reworking, new MC excavations
Gyepű Hill 30 ha (Fig. 6d)	8 small veins, pitholes concentrated along Baglyas Valley sporadic holes on the tops,	More adits (up to 10) following the veins	János central ventilation shaft András shaft	Sporadic debris reworking in pits and dumps

Soil Studies

Soil survey was carried out on the well-accessible Sinta Hill (Novák and Szepesi 2018), where many new mineral collecting pits were excavated (Fig. 6c). The 0.5–1-m profiles of Umbrisols and Cambisols (relatively young soils with little profile development) were developed on the hydrothermally altered andesite and dacite. Based on soil profiles and field work observations, the medieval mining produced layers of mining waste deposited on original slopes. This material was excavated just from the direct vicinity of the surface. Since the abandonment of mining, the debris was undergone to further weathering processes and could not be evaluated as artefacts, but as Transportic (mechanically reworked), and Novic (a layer with ≥ 5 and < 50 cm thickness) material over the original soil horizons, in case it could be even distinguish from it. *Profile 1* is located on the edge of an abandoned medieval open mine pit (Fig. 6c); it represents the soil, which is developed on weathered, hydrothermally altered rhyodacite, which is not covered by later, anthropogenically translocated mining waste or debris. The surface farther

Fig. 9 Mineral collecting disturbances in the study area. **a** Large, fresh excavation at the top of Kánya Hill; the rims between two medieval pits merged, with well-visible filling at the bottom. **b** The excavations open and cut the root zones of the trees and these easily fell over. **c** Reworked surface debris with open root zone at Király Hill nature conservation area. **d** New deeper (1 m <) mineral excavation pit. **e** Fehér Hill, and university field work, the quarry classified as extensive site for public collection, minerals see on Fig. 4c–f

around the pit is slightly elevated by redeposited material excavated during mining, but in profile nearly original soil surface was visible. Therefore, in the case of *Profile 1*, recent anthropogenic influences are not obviously recognizable. *Profile 2* is at a shallow pit, excavated by hobby-mineralogists, in fresh, dark gray 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, suffix qualifier applies, with addition of the texture class of the fine part of this reworked material: Siltynovic (silt or silt loam texture). At *Profile 3*, the surface is covered by 20-cm-thick redeposited soil material, which together with the original topsoil horizon fulfils the minimum thickness criterium for umbric (≥ 20 cm, dark, low base saturation, moderate-high organic matter content), that means, it gets part of the umbric horizon, but it is at the same time Transportic, and responsible for Siltynovic character. For detailed explanation of WRB reference groups, pre- and suffix qualifiers see IUSS Working Group WRB. 2015.

Degradation Risk (DR) Estimation

Degradation risk was estimated using the criteria set of Brilha (2016, Table 2). For the regions, most intensively affected by mineral collecting, not only the main geological value (minerals) but also the geomorphological landforms (secondary/attributed value) of mining and soils, are also damaged (Fig. 9a). Based on this, they were classified in the category *damage of all geological features* (4 points, Kánya, Sinta hills). In other areas, we classified this measure as damage to primary or secondary geological values (3 or 2 points). In the case of *proximity of activities to cause degradation*, the distance of nature trails was used. But in this respect, the general geotourist visitors and mineral collectors cannot be distinguished. Based on this, the subregions along a nature trail scored higher values, while peripheral objects scored lower. The *legal protection* is only applicable for the Király Hill (Fig. 6b), as it is located in the Zemplén Landscape Protection Area and is also a Natura 2000 site. The *accessibility* is a more important indicator, as there is a parking and resting area next to Király Hill (4 points, Fig. 6b and c). Sinta and Kánya hills are also easily accessible from asphalt roads (3 points). Veresvíz, Fehér, and Jó hills are located next to a nature trail (2 points). Only the area of Gyepű Hill is more difficult to access (Figs. 2 and 6d, 1 point). The *density of population* is irrelevant to the activity of the target group, but the population density of the study area is low (1 point). Based on this, the highest scores were obtained for Sinta, Kánya, and Király hills (330–350, Table 4), which are classified as high degradation risk (DR 300 < high). The 3 sub-areas along the nature trail are classified as medium risk (DR = moderate), while the lowest score is for Gyepű Hill (195, DR = low).

Discussion

Geotourism essentially focuses on geology and landscape including landforms, rock outcrops, rock types, sediments, soils and crystals, and 'process', such as volcanism, erosion, and glaciation (Chen et al. 2015; Newsome and Dowling 2018). These are in situ occurrences of geodiversity elements. The ex situ (or movable) elements (minerals, fossils, and rocks) of geoheritage are displaced from their natural location (Brilha 2016) but, when stored in museums and special collections, they also have an important educational, aesthetic, and cultural value for the society. Unfortunately, the movable geoheritage elements have been in danger in the last decades. The growing number of mineral and fossil collectors, and commercial collecting are a major problem (Gutiérrez-Marco and García-Bellido 2022). This situation needs to promote proper conservation and management of the moveable geoheritage and requests detailed field studies focusing on geosite sensitivity and vulnerability assessing risks and impacts. The paleontological heritage has a greater focus (e.g. Manni 2012; Francisco and Carvalho 2016; Tavares et al. 2020; DeMiguel et al. 2021) with case studies. Although the business case is even stronger for minerals (de Brito Barreto and Bretas Bittar 2010), the number of case studies dealing with this is small.

The Tokaj Mountains and medieval mining area of Telkibánya are among the oldest researched areas in the Carpathian Basin, representing a complex geological-geomorphological industrial-cultural heritage. The first studies were carried out during the Neptunist-Plutonian controversies (Fichtel 1791; Esmark 1798; Richthofen 1860). The hydrothermal formations associated with Miocene volcanism and the raw mineral exploration were given a prominent role for the mountain and Telkibánya. As a result, the mountain range is also an important target area for amateur mineral collecting in Hungary with 1/6 of the documented mineral deposits (112 sites, Fig. 1a), of which the study area is one of the richest with up to 20 documented sites. Unfortunately, site-specific impact assessment for conservation purposes has not been carried out. In the study area, the previous work of Balázsi (2013) documented disturbances of the Kánya Hill and attempted to raise awareness of the problem. Subsequently, the Aggtelek National Park launched a mountain scale, site-based geoconservation mapping (2015) which included parts of the study area. The detailed field survey of Telkibánya mining area was carried out in 2018.

The geosite assessment (Brilha 2016) defined that a site has a high degradation risk when the main and/or secondary geological elements have a high probability of being damaged by natural or anthropic factors. In the study area, the mineral paragensis is the main and the explored mining heritage is the secondary geological element. The minerals developed in lithophysa holes (geode) of rhyolite, rhyodacite, and in vugs of brecciated zones (Fig. 4). Carving individual holes and/or evidence of surface debris collection were ubiquitous in the whole study area They are finite resources, where the collecting removes them from their original place. The degradation risk of the secondary geological elements affected the mining heritage and the soils. Our results with soil profiling provide compelling evidence for the long-term (decades) surface disturbances of collecting. Without controlled collecting, there is no information about extracted minerals (species, size); these can only be found on mineral market or in private collections. The most affected region was Kánya Hill (0.5 ha) and Sinta Hill (0.1 ha) area (Fig. 6a

Table 4 Weighted score of degradation risk estimation; for details of weighted factors, see Brilha (2016)

	Kánya Hill	Sinta Hill	Veresvíz pitfield	Joó Hill	Fehér Hill	Gyepű Hill	Király Hill
A. Deterioration of geological elements	4	3	2	2	2	2	4
B. Proximity to areas/activities with potential to cause degradation	4	3	4	4	4	1	4
C. Legal protection	4	4	4	4	4	4	2
D. Accessibility	3	3	1	1	1	1	4
E. Density of population	1	1	1	1	1	1	1
Total (weighted)	**355**	**355**	**235**	**235**	**235**	**195**	**330**

and c). Here, the objects of medieval pit mining have been transformed with the degradation of primary (mineral) and secondary (mining landforms, soil) geological elements. The pithole margins have been reworked, and long ditches were formed (Fig. 9a and b). The weakened root zones of the trees cause them to dry and fall which resulted in biotic degradation (Fig. 9c and d).

The degradation risk of the subregions included accessibility options (Table 2). Excavation needs special, heavy toolkit (spades, picks, shovels); therefore, the well-accessible regions are the most affected (DR 300 <, high). The Sinta Hill and Kánya Hill excavations are also in 500 m distance from a local road. Király Hill is accessible by a regional road and there is a resting place with car and bus parking. Regions with moderate DR values (200–300) are situated along the geotouristic nature trail. Large excavations have not been identified here.

The soils' sequences show typical material developed on the weathered silicic volcanic rocks, containing relatively large proportion of skeletal parts. Anthropogenic influences are still recognizable, but in the described soils, the taxonomy is reflecting them only at the level of supplementary qualifiers. Based on control observations over several years, the age succession of collecting sites proved that once disturbing activity ceases with the emergence of leaf litter accumulation and bioturbation is difficult to identify after 3–5 years.

Geoethics

Human actions have an impact on natural processes and the environment (DeMiguel et al. 2021). Taking this into account, geoethics as a young multidisciplinary field represents an opportunity for geoscientists to become more conscious about their social role and responsibilities (Di Capua and Peppoloni 2019; Sütő et al. 2022). Geoethics is also a tool to raise the awereness of the society on problems related to geo-resources and geoenvironment. The main reasons of collecting geological specimens are scientifc research, commercial purpose, education, observation, and private collection. Collecting is enjoyed by many people as an inspiring experience of abiotic nature and also important for science. The amateur collectors have not only enriched our knowledge about the geology of Hungary but, without their enthusiasm, the collections of museums and natural history departments would also be more modest (Mezei and Prakfalvi 2016). Beside this, smuggling and illegal collecting mostly affected vulnerable fossils, minerals, and rocks feeding the national, international trading networks (penzcentrum.hu).

In the case of Telkibánya, regarding ex situ (movable) geoheritage, both regional and national collections contain a large number of specimens from here. However, the number of specimens for scientific and educational purposes is not significant. The minerals extracted in the largest quantities are removed for commercial purposes and/or placed in private collections.

Regarding the legal aspects for collecting, the following major cases shall be considered:

In Hungary, Act LIII of 1996 specifies that minerals, geological remains, and their significant deposits should be declared for potential protection. This was further regulated by Decree 21/2007 (20.VI., net.jogtar.hu) KvVM on the scope and monetary value of protected minerals and mineral associations, but its enforcement has not been successful. In recent years, Decree 55/2015 FM was adopted, which sets out site-based protection with defining the conditions for scientific research and collection with a detailed management plan. Regionally, our study is partially connected to this geoconservational mapping, including some sites affected by mineral collecting.

In the study area, collecting is not under any control. At Király Hill, collecting without a permit is illegal (geomania.hu) but nature conservation authorities are unable to provide permanent supervision. Regarding attitude segmentation of fossil collection, high environmental attitude and low environmental attitude groups were defined (Kim and Weiler 2013). The first case is applicable to amateur collectors while the second group represents the extensive commercial collecting. Earth sciences are in a rather backward position regarding social respect and educational role; therefore, it is important to raise the awareness of young people who are interested. Accordingly, opportunities for geo-amateur collectors should be maintained while commercial collecting with the addressed geoethical problems deserve a more suitable legal framework.

Management and Geoconservation Issues

The integrity of geosites and geotourism attractions is usually weakened by natural and human threats (Pourfaraj et al. 2020). The significant threats of geological sites may include the loss of geological exposures (building, vegetation), removal of irreplaceable features (minerals, rocks, fossils, soils), and damage to geomorphological features (Prosser et al. 2006). Documenting the affecting activities allows a rather comprehensive assessment of the exploitation patterns (Ruban et al. 2022) enhancing an effective geoconservation.

Mining landforms as anthropogenic geoheritage usually generate enhanced tourism interest (Kubalíková 2017). Telkibánya is one of the main geodiversity hot spot regions in the Tokaj Mountains (Szepesi et al. 2020; Ésik 2022) with high scientific, aesthetic, touristic, and geo-educational potential. This is emphasized by the establishment of a nature trail (Hartai and Németh 2012) and a university education center for geological fieldwork trainings Telkibánya is also a location for Hungarian Geosite Day (Sütő et al. 2020, geotopnap.hu) including visit to the mining museum. Both university education and geotourism have an important role to raise awareness of the importance of minerals as movable geoheritage and to promote ethical collecting. Recently, we held a geotourism course (Sütő et al. 2022) organized by the Bükk National Park, in which mineral collecting was included in a separate chapter. This could be adopted in the future in this region to involve the local population as tour guides.

Regarding movable geoheritage, Telkibánya is an outstanding mineralogical site which emphasized by scientific relevance (e.g. Szakáll and Weiszburg 1994; Molnár et al. 2009; Ésik 2022). However, as potential threats are being posed, their preservation needs geoconservation actions with (geo)site-based guidance. As it was mentioned, the study area was divided into 6 main subregions (Fig. 6). From these, the Király Hill area is situated inside the nature conservation area (Fig. 6b). In the course of the fieldworks, over 1000 objects were mapped for Aggtelek National Park including the detailed survey of the mineralized area. Unfortunately, only the feeder dyke of Cser Hill rhyolite dome is protected under Decree 55/2015 and it is located outside the study area (Szepesi et al. 2020). Based on the experience of the field survey and international practices (Natural England 2012; Crofts et al. 2020), we try to define territorial proposals for enhancing a geoconservation strategy.

The British geoconservation practice (Natural England 2012; Crofts et al. 2020) defined three different types of geosites to aid site management: exposure (or extensive), integrity, and finite. The exposure (or extensive) sites contain geological features that are relatively extensive beneath the surface. The integrity sites are active geomorphological systems (e.g. karst) and not applicable here. The *finite sites* contain geological features with limited extent where removal may damage (or destroy) the resource. As an international example, the Lampivaara amethyst mine (amethystmine.fi) is a good instance for controlled collecting, where there is a size limit above which the specimen remains the property of the mine, smaller specimens can be taken away by the collector.

Based on the above, all mining objects of the study area can be classified as finite site. The dacite geodes of Sinta Hill filled with quartz and zeolites are unique with limited extent; their removal is irreplaceable, while the occasionally operating quarry at Fehér Hill (Fig. 9e) is an exposure site where the periodic excavation of Fehér Hill does not cause significant depletion of the resource. Using this vulnerability-sustainability approach site-based management can be based on well-defined types/zones as open collecting, open-managed collecting, and controlled collecting (Table 5). Open collecting is appropriate in extensive sites where the threat from collecting is low and other management issues are not applicable. Open-managed and controlled collecting are appropriate for finite sites. In protected areas (Király Hill, Fig. 6b), collecting is can be subject to National Park authorization. At other currently unprotect sites with high DR (300 <, Sinta Hill, Kánya Hill), collecting needs to be more carefully managed. Here, after a possible declaration of protection, all collectors would be obligated to obtain a license. Even size (quartz crystals) and mineral type restrictions can be implemented under appropriate professional supervision. The best practices for controlled collecting include special safety features (controlled access, special fencing) which do not currently exist in Telkibánya mining area. Controlled access in the form of an entrance fee could enrich the local community financially.

These would also serve safety purposes which is also an important aspect of geotourism destinations. Most of the mining heritage objects (see air ventilation shaft; Fig. 7d) even along the nature trail are accident prone and should be approached with caution.

In Hungary, there was also a proposal to classify collecting (picking – without tools, collecting – with tools), collectors (occasional collector, authorized collector, professional institution), and the collecting sites (unprotected, protected, protected with high priority), but the initiative was unfortunately abandoned due to other conservation concerns. Brazilian policy

Table 5 Types of collecting based on legal regulations and control aspects (based on DeMiguel et al. 2021, Natural England 2012)

		Application in the study area
I. Illegal	— When it does not follow local and/or national collection regulations	Usually without the owner's and nature conservation permission
II. Legal	— When it follows local and/or national collection regulations	Currently not applicable in most cases
IIa Uncontrolled (Open controlled)	Threat from collecting is low, done in areas without specific or appropriate collection regulations	Fehér Hill quarry (Fig. 9e)
IIb Open-managed collection	Vulnerable site and with responsible collecting and appropriate restrictive approach	Most of pit fields (Fig. 6 and Table 4)
IIc Controlled collecting	Finite resources with effectively controlled access	Current and proposed nature conservation areas (Sinta and Kánya hills, Figs. 2 and 6)

(Kuhn et al. 2022b) also emphasize that some geodiversity elements such as fossils and caves have specific legislation. The United Nations Educational, Scientific and Cultural Organization (UNESCO) promote the development of policies in different countries as an international framework. These issues are important and must be addressed in sufficient detail in geodiversity-related development projects (e.g. geopark proposals). Our study tried to provide a case study and proposal on this, partly adopting relevant international practice.

Conclusions

Hydrothermal deposits and mining landforms have a great potential for geotourism development. But minerals as movable geoheritage and their collecting emphasize conflicts between earth sciences, geotourism, and geoconservation, degrading primary and secondary geological elements of geodiversity. In the Telkibánya area, our fieldwork with soil survey proved that surface excavation highly influenced the geological environment and the medieval anthropogenic geomorphology causing loss of information stored in finite mineralogical association and historic mining landforms. Some mineral species have been almost completely removed from natural occurrences. The geo-amateurs with high environmental attitude are important for mineralogy providing resources for the identification of new minerals in Hungary and worldwide. There is also a demand from them for collection to take place within a legally regulated framework (e.g. Brazil, Finland). This underlines the importance of site-based protection and continuous control on different target groups in collecting (geo-amateurs vs professionals).

The educational, cultural, economic, and social value of the mining heritage is obvious for the Telkibánya community. Our geodiversity and geoconservation action plan may help to make geoheritage resource exploitation sustainable while objectives, regulations proposed here serve to ensure the importance of abiotic nature. In protected areas (Király Hill, Fig. 6.) and regions with highest DR value, collecting is clearly prohibited, while outside these areas, collecting should be allowed for the high attitude group under control (authorization) and continuous monitoring. The disadvantage is that it requires legislation and human resources, which can only be provided by regional development projects based on geodiversity (e.g. geopark proposals).

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Declarations

Conflict of Interest The authors declare no competing interests.

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