International Cartographic Association
Association Cartographique Internationale

Geosite database of the High Gerecse Hills (Hungary): with cartographic and GIS-based methodologies

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Abstract: Geotourism is a branch of tourism that primarily presents the inanimate and spectacular objects of nature that sustainably have scientific and tourism significance. Although in Hungary, activities connected to it are not widely spread yet, the sector is dynamically developing. Dissemination of geotourism values is primarily concentrated in geoparks. The main goal of these institutions is to preserve and popularize geoscientific (geological, geomorphological, soil, landscape) values. We consider all inanimate geoscientific, social, cultural, or religious values as geosites, which carry scientific content in an easily interpretable and spectacular way for visitors. Geosites are the most important objects of these organizations. When founding a new geopark, the first step is to identify geosites by using cartographic and database materials and with some additional fieldwork. In our research, we conducted a survey of this kind in a geotouristically undiscovered, midmountain area in Hungary. After analogue and digital data collection, we identified all the geologically valuable objects in 16-day-long fieldwork. A digital Leaflet-based database has also been prepared encompassing the results of the field survey, which can be a basis for further research and infrastructural development.

Keywords: geosites, field survey, database, cartography, GIS

1. Protection of geoscientific heritage

Protection of geoscientific heritage is a relatively young but increasingly important branch of geosciences. First international and Hungarian papers on this topic were published in the middle of the 19th century (Gellai & Baross 2005, Tardy et al. 2006), but the protection of inanimate values did not have an organizational background until the end of the 20th century. All the elements of geodiversity (geology, geomorphology, pedology, hydrography, mineralogy, paleontology) are less known among the general public than the concept of biodiversity. However, at the same time, the living environment (biosphere) cannot exist without the inanimate components of planet Earth (geosphere) – geodiversity is the foundation and source of every kind of life on the globe (Gray 2004).

Visible milestones of the 4.6-billion-year history of our planet are preserved by the elements of geoscientific heritage protection, and the identification, evaluation, maintenance, protection, and sustainable touristic activities carried out on them (Szepesi et al. 2018). At the international organizational level, this field is currently managed by the International Union of Geosciences (IUGS) and the International Association for the Conservation of Geological Heritage (ProGEO).

In our research, the goal is not only to identify and collect these special landmarks into a database but also to communicate them to decision-makers. In this way, these objects and their scientific value can become well-known and interpreted: the sites can achieve protection and can serve as the main disseminators of scientific knowledge. International Geodiversity Day (6th October every year), an initiative approved by UNESCO will hopefully contribute to the development and spread of the geoeducational role of this scientific field (Horváth 2022).

1.1 Geotourism

Geotourism is a relatively new branch of tourism that is based on the sustainable utilization and presentation of geoscientific values. In almost all cases, these refer to inanimate geological, geomorphological, pedological objects, landscapes, and other formations. It includes all special landforms through which people can learn about the values of earth science heritage (Dowling 2011). Dowling and Newsome (2006) recommend presenting processes and landforms to tourists through field ‘learning’ activities – this was the basis for the formation of the concept of geoeducation. During guided hikes, presentations, and various outdoor activities, visitors can gather background knowledge with the help of trained guides of the geosites or by using spectacular and illustrated material in visitors’ centers. Geotourism deals with the presentation and promotion of these values in balance with protection, maintenance, and sustainability. Leading actors of geotourism maintain a close connection with decision-makers and institutions of geoscientific heritage protection – e.g. the Bakony–Balaton Geopark has a close relationship with local municipalities and universities in Hungary.

The most important objectives of the (geo)touristic and the scientific sector are recognition, assessment, and protection of the value of inanimate natural formations.

Advances in Cartography and GIScience of the International Cartographic Association, 4, 10, 2023.
31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-4-10-2023 |

Geosites are the most spectacular and important elements of geotourism. These objects can be of various types, connecting the inanimate environment with various parts of everyday life with additional social (e.g. the amphitheater in Alsőörs built of local red sandstone), cultural (e.g. Friars' habitation in Tihany), religious (e.g. churches that are built of typical local rocks), and ethnographic values (e.g. special ethnic words for geological formation or soil types). Geosite types also show a diverse image in terms of natural formations: basic geological sections, rocks, caves, large and spectacular stone areas, or even the landscape itself (Pál and Albert 2018). Locations of geosites are mostly open to everyone, thus qualified researchers and visitors who are less aware of geological knowledge but are interested in interpretable scientific content can visit them freely. In addition to heritage protection, geotourism can also enhance economic development for the local population, as it provides an income opportunity. Moreover, geosites with their scientific become part of the identity of the community (Grant 2010, Dowling 2011).

Geotourism is most widely present in geoparks. Geosites are the basic building stones of these organized institutions. Geoparks can be discovered all over the world, they form the institutional background of heritage protection and sustainable tourism in each country where they are founded. The Global Geoparks Network (GGN) and local networks in the continents provide a professional forum for scientists, geopark staff, and contributors to share good practices and experiences (McKeever & Zouros 2005).

1.2 Aims of this study

In our research, we designated an area that was barely explored from the side of geoheritage protection and tourism. The High Gerecse Hills in Hungary are rich in geoscientific value. Visitors can encounter diverse objects, and spectacular geoscientific formations in the area, which have significant cultural and ethnographic connections. As the first step of the research, we determined the potential geotopes (this word is a synonym for the word geosite) based on the available maps and materials from sources, which we summarized in a spatial database. Based on the information that can be interpreted from the data sources (topographic maps, geological maps, scientific publications, and databases), we classified the potential sites into lithological categories (e.g. young fluvial sediments were considered less important, while older rocks were considered important) and categories of accessibility (distance from roads, paths, settlements). This classification provided the basis for fieldwork, that was needed for validation and photo documentation. After summing up the results, our geodatabase provides a comprehensive image of the most important geosites of the investigated area and their spatial distribution. This database can be used for further geosite assessment purposes and decision-making when planning infrastructural touristic developments.

2. The High Gerecse Hills (Hungary)

The region of the Gerecse Hills is one of the richest regions in Hungary in terms of geological and geomorphological treasures (Fig. 1). The sample area in the research is the High Gerecse Hills, located between the Danube (to the North, also as the Slovakian border), the Hills of Vértes and the city of Tatabánya to the South, and the Lower Gerecse Hills on the South. This range is located in the north-western part of Hungary and is a part of the Transdanubian Mountain Range.

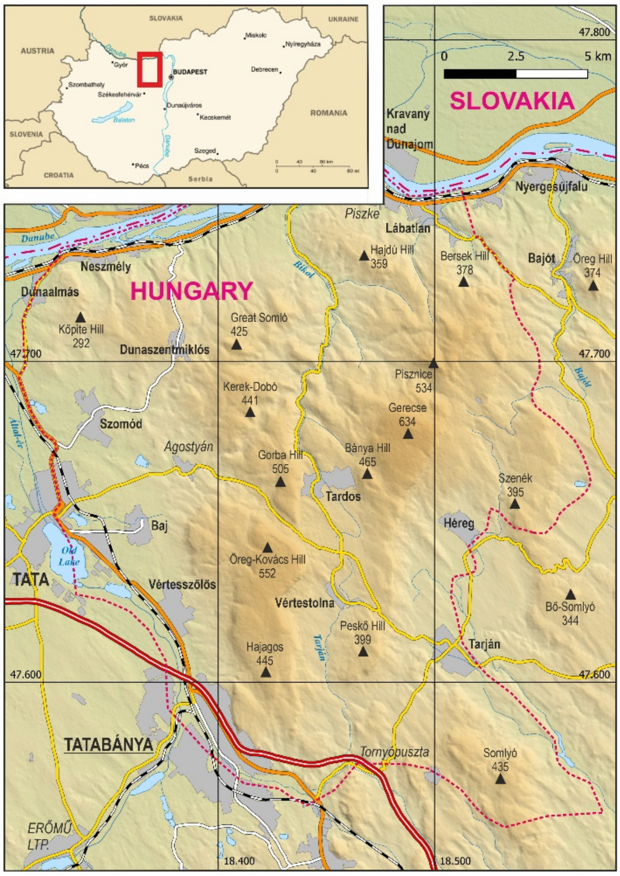

Figure 1. The High Gerecse Hills (Hungary)

2.1 Geographical overview

The Transdanubian Mountain Range shows great diversity in terms of geomorphological structure and landforms. The surroundings of the highest peaks (e.g. Kőris Hill, Som Hill, Nagy-Kopasz) are mainly carbonate plateaus. Here, the climate has mountainous attributes, and these areas are primarily used for forestry. The lower areas are special because of the slightly undulating plateau surfaces, steep slopes, and strongly raised edges with cliffs and rock outcrops. Here we can find dense valley networks and fast-flowing small streams. The main body of carbonate formations is made even more diverse by the occurrence of volcanic mountains (e.g. Badacsony and Saint George Hill in the Tapolca Basin), intermountain basins, trenches, and depressions (Tardos Basin), as well as plains and alluvial surfaces (Dövényi 2012, Juhász 1997).

The Transdanubian Mountain Range has a subcontinental climate, but in some areas (e.g. the Balaton Uplands) sub-

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mediterranean influence prevails. In addition, characteristics of zonal mountain climates are recognizable in higher territories. In the mountain range, the distribution of precipitation is relatively balanced, it ranges between 500 and 900 mm. The landscape belongs to the moderately cool-moderately dry version of the continental climate. In the mountainous fringe areas and in the eastern part of the Gerecse, the average annual temperature exceeds 10 °C, while in contrast, this value is below 9 °C in the other parts. (Dövényi 2012).

The High Gerecse is the most fragmented microregion of the Transdanubian Mountain Range. The main area of our sample area is covered by a series of boulders, while in the western part, steep basins can be found (Csorba 2021). Gerecse is rich in karst formations: several caves, dolines, and carbonate formations have been developed on the plateaus, e.g. on Nagy-Gerecse and Nagy-Eménkes (Juhász, 1997).

Being a karst region, the mountain range is poor in terms of hydrography. Surface watercourses are only scattered, and the number of natural lakes is also low (Barina 2006). Regarding environmental protection, Gerecse is a significant area as almost half of its area (41%) is part of the Protected Landscape Area of Gerecse, and an even larger area (70%) belongs to Natura 2000 areas (Csorba, 2021).

2.2 Geological overview

The Gerecse Hill**s** form the NE part of the Transdanubian Range Unit syncline structure. Its higher area lies on the west, bordered by the Danube and its basin. The eastern lower area extends as far as the Basins of Zsámbék and Dorog separating it from the Buda Hills.

The Gerecse Hill**s** is mainly built up of Upper Triassic shallow-marine carbonate rocks composed of Main Dolomite (with a thickness of more than 1000 m) and Dachstein Limestone, overlaid by a thin Jurassic succession (with a maximum of 50-60 m). There is a hiatus with varying extents between Triassic and Jurassic, but Lower Cretaceous layers conformably follow them with marl and conglomerate. All formations from pre-Cenozoic times have undergone erosion or local karstification – these modified forms were overlain by Eocene succession. These formations are clayey-marley rocks, brown coal, and some carbonates that were followed by Oligocene clay, silt, and sand. Miocene formations are rather unknown in the vicinity of the Gerecse Hills. Loess, aeolic sand, and fluvial deposits have the largest areal extent that is followed by travertine bodies.

This geological history is visible through the current tectonics of the area: young faults with N–S and NW–SE directions characterize the landscape, and Mesozoic blocks are bordered by high and steep walls with beautiful outcrops. Paleogene sediments form layers among these blocks in intramontane valleys that follow fault lines (Budai, 2018). A lot of key sections, quarries, and other natural outcrops represent this rich and diverse geological composition – these were analysed in this study.

3. Methodology and data processing

Our workflow consists of five main steps:

- As the first step of the research, we started collecting source material on designated data.
- After digitizing possible point-feature elements, we filtered and classified them according to their lithological and potential touristic importance (difficulty of accessibility and distance from roads and settlements).
- Fieldwork
- Fieldwork was followed by the analysis and digital presentation of the results in a web environment.
- As a final step, we received a comprehensive image of the geosites of the area that has a potentially high geotourism value.

3.1 Data collection

A large-scale map of the area showing geotourism content has not been prepared yet. To identify potential geosites, we examined sheets of 1:10,000 scale Hungarian civilian topographic map series (Unified National Map System of Hungary, abbreviated from the Hungarian title as EOTR) and 1:25,000 scale Gauss-Krüger military topographic sheets as cartographic material. From the maps, we digitised potential geosite objects (e.g., rock, cave, rocky area, spur, hollow, cave, etc.) in QGIS (3.20.3), and organized them into a geodatabase. It is important to mention that the used civilian and military topographic map sheets are quite old (they were edited in the 1980s), and their content may be out of date (e.g. there are new built-up areas, road networks, and quarries at some places, while old ones have already been abolished). In addition to the topographic sheets, we processed material-from other sources, too. An example is Főzy & Szente (2007), a scientific book dealing with fossil remains of the Carpathian Basin and describing their locations Furthermore, based on the maps on the official website of the Hungarian Mining and Geological Service, we also digitized the most important mineral sites.

Based on the 1:50,000-scale geological map of Gerecse Hills and its explanatory booklet (Budai et al. 2018), lithological attributions of each potential geosite were identified and included in the database: we noted the formations where the objects are located in the digitized map dataset. During the construction of the database, we highlighted the most important site attributes: lithological index, corresponding toponym, and landform type for each location. We also indicated the source material, and text identifier of the point-feature objects. In its final state, before filtering, the database contained approximately 1,900 items.

3.2 Data filtering

From the database, we filtered the points following various aspects. First, with OpenStreetMap (OSM) and Overpass Turbo, a free OSM-querying service, we selected the point elements from the database that are located in built-up areas and are most likely no longer exist in their original positions due to artificial modifications of the landscape (e.g. due to construction works). This step was necessary because there have been significant changes in the development of settlements and their near surroundings since they were surveyed. We deleted all the lost and changed points from the database.

The second filtering criterion was the type of bedrock on which the recorded potential geosites are located. Based on the 1:50,000 scale geological map of the Gerecse Hills and the lithological indices of the features, we determined formations and rocks that are assumed to have no special scientific and touristic value. This group includes various stream (fluvial) and slope sediments, or artificial fills. The set of these points was classified into the *less important* group.

The third filtering is based on the location of the geologically more important objects related to hiking trails. For this process, we downloaded all the hiking trails in the area as vector files with Overpass Turbo. After loading them in the GIS software, we created a 1,000-meter buffer zone around the roads (1,000-1,000 meters on both sides). The sites within this zone are classified as *important objects*, and the ones outside the buffer zone are classified as *moderately important objects*. We recorded geological key sections in a separate category, as they all have high geoscientific value. After filtering, three categories were created: *less important*, *moderately important*, and *important* points, completed with the geological key sections.

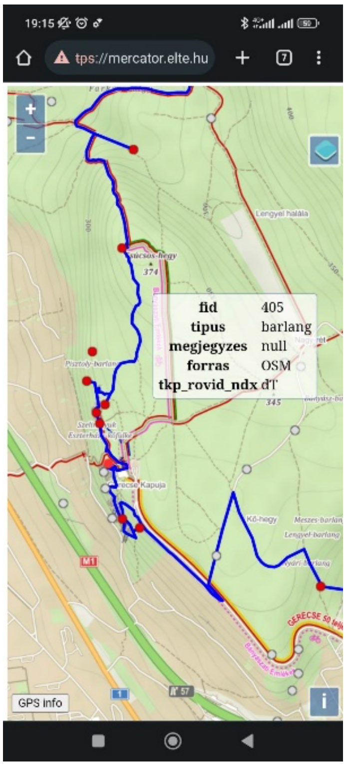

Figure 2. Mobile phone screenshot of the web map in use in field navigation

3.3 Fieldwork

The next step of the research was the pre-planned fieldwork. In total, we worked 16 days in the area on validating data recorded from the cartographic sources.

3.3.1 *Preparation for the fieldwork*

Before hitting the trails, we prepared a web-based fieldwork application containing all planned routes and recorded potential geosites. For that, in QGIS, we created optimal routes that connect all the *important* points, and as many *moderately important* points as possible to check during our working days in the Gerecse Hills. The routes were uploaded to the Leaflet-based web app that was used on the field for navigation (Fig.2). We also uploaded all the categorized points and routes to the smart map.

In this web application, we can also select different routes and categorized points. The website is available on mobile phones as well (download at http://mercator.elte.hu/~edina/gerecse). In the interactive map, potential geosites are displayed as point-feature elements next to the planned routes. By clicking on these points, popup windows provide attributes of type, geological index, and name of the recorded sites (Fig.3).

When planning routes, we faced the problem that some important and several moderately important points were in restricted areas or in areas where entry required permission. It took us some time to receive permission from the authorities and we were able to enter these areas. In addition to the highly protected areas, there were *important* points and geological key sections that were found in operating quarries. In these cases, we were allowed to visit these places only on weekends with special guidance.

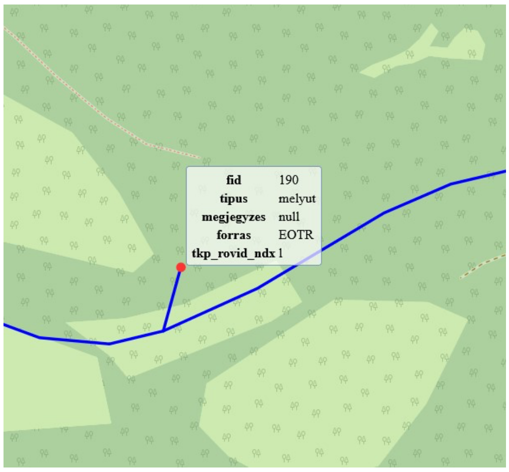

Figure 3. Attributes of a potential geosite in the field web app

3.3.2 *Fieldwork and updating the database*

During fieldwork days, we visited all the *important* and most of the *moderately important* points and we recorded every change related to the geosites. Together with the web application, a paper-based map was prepared, too and corrections were also applied manually. Some objects had already been destroyed due to natural or human intervention some of them had disappeared, while other

 https://doi.org/10.5194/ica-adv-4-10-2023 |

objects were overgrown with vegetation - we removed these points from the database. There were objects that we explored in the field but were not indicated in the base data maps, and therefore these were not included in the initial digital database either. We recorded the new points with photos and later uploaded them to the geodatabase using QGIS. We have visited 413 potential geosites during fieldwork.

4. Digital database and web-based map

After the field survey, a new informative database was created that contains the following information for each geosite: type (rock, cave, geological base section, etc.), source (OSM, Gauss-Krüger topographic map, fieldwork date, route, etc.), lithology, comments (name, importance, accessibility). In order to publish the results of our research, we have created a website (*https://mercator.elte.hu/~edina/ogp/index_en.html*) on the server of the Institute of Cartography and Geoinformatics at ELTE Eötvös Loránd University where the database can be viewed on a map with some additional information about the geosites, the sample area, and the overall concept of geoheritage.

4.1 Online webpage

We displayed the surveyed points and the geosite database of the High Gerecse Hills in a web application (Fig. 4.), which is more visual and user-friendly than a simple database. The completed web platform consists of two main parts, the main page, and the sub-pages. The opening page briefly introduces the topic to the users: what information they receive when scrolling down. In the upper right part, there are several useful links about the theoretical background of geoheritage. By clicking on them, the page navigates to the given section, to read the sought information.

All of the pages on this website are based on HTML, using JavaScript (with Leaflet) and we created the styles using CSS.

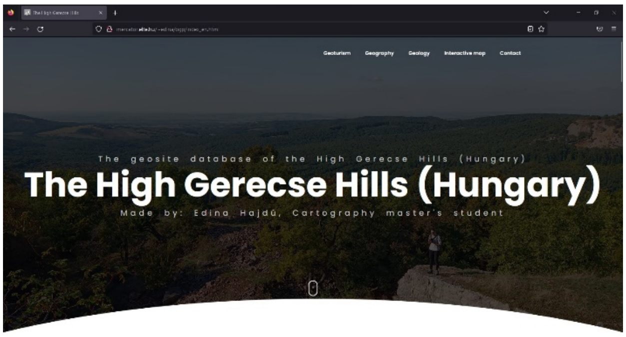

Figure 4. Opening page on the website of the geosite database of the High Gerecse Hills

4.2 Leaflet map with the digital database

The most significant outcome of our research is an interactive web map that readers find at the bottom of the High Gerecse Hills initial webpage. In this web map, the default background map is OpenStreetMap (Fig. 5) but users are allowed to choose different background maps as well. Geosites are indicated with red dots. By clicking on them, a popup window opens with data of the selected geosite like the name of the location and rock type. We used the Leaflet JavaScript library for scripting the map and the fields of the database in the popups.

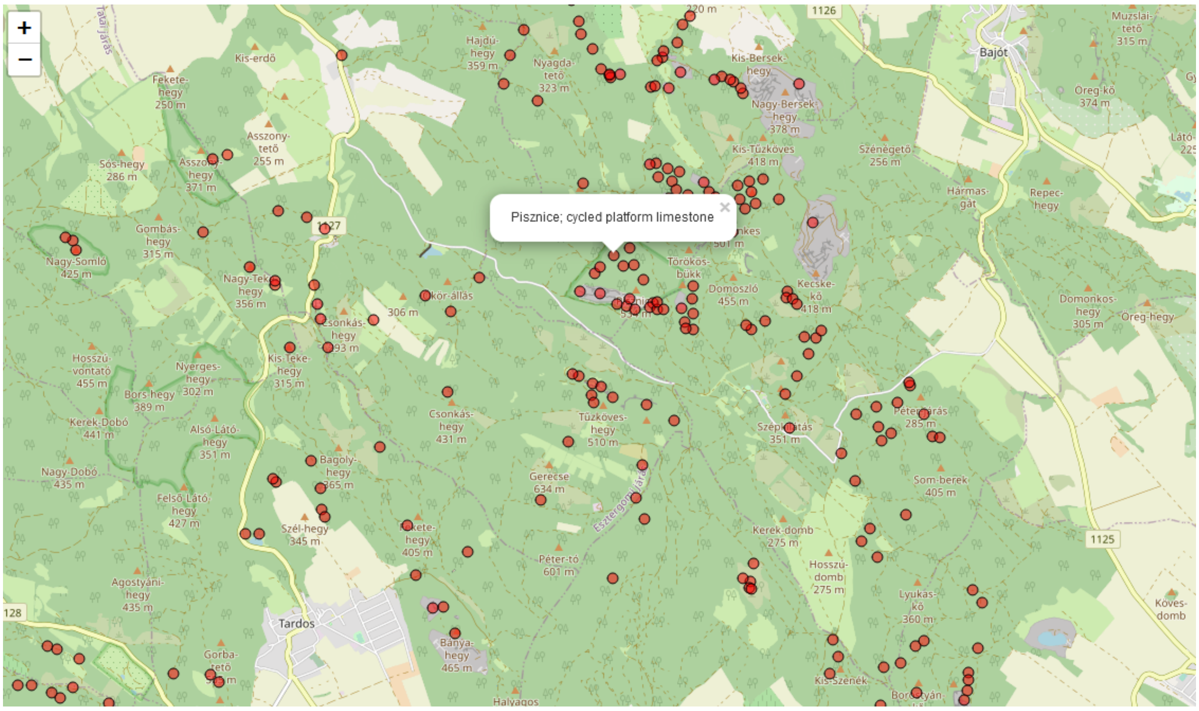

Figure 5. The final map containing the identified potential geosites

4.3 Sub-webpages

At the bottom of the main page, readers find links to various subpages. The *'Database'* subpage contains the complete database with all the records of geosites in the High Gerecse Hills. The Database subpage was created in the following way: we first saved the attribute table from QGIS software and loaded it into Microsoft Excel. After that, we generated the database as an HTML table, edited its style in CSS, and inserted it into the High Gerecse Hills website as a subpage. Users can find the smart map we designed for fieldwork days in the '*Fieldwork'* subpage. The most spectacular subpage is the one called *'Field pictures'*. Here, a gallery of the pictures taken during our fieldwork provides insight into the most important forms and landscapes of the geosites in the High Gerecse Hills database. We made our photo selection on a subjective basis as no quantitative geosite assessment has been done yet. In order to present the geosites and their surroundings in the most informative way, we added short descriptions to the pictures. Under the pictures, we first indicated the names of the geosites, and then we attached a short description of them.

5. Conclusion and discussion

This paper presented the steps of identification of the most important geoscientific objects in the High Gerecse Hills (Fig. 6). By establishing a workflow based on various cartographic material, GIS databases, and fieldwork, it gives a workflow for other areas all over the world to follow. The proposed database structure includes all information about the identified potential geosites that can be the subject of a later evaluation and geopark establishment. The resulting website makes the database easy to interpret, as each surveyed object is assigned to an exact location. Decision-makers, management bodies, and the related national park directorate can easily access the entire database, which also includes additional information about the process.

Figure 6. Pes-kő, one of the most important geosites of the High Gerecse Hills (due to the limestone platforms, a cave, and the sight)

Before planning any development of touristic infrastructure, it is necessary to evaluate the collected sites with geosite assessment methods. This procedure is carried out with the GAM (Geosite Assessment Model) and the M-GAM (Modified Geosite Assessment Model) methods in the near future (Tomić & Božić, 2014, Vujičić et al. 2011). Both evaluation methods take several aspects into account during the evaluation such as accessibility, interpretability, and the presence or absence of information boards. The specific location receives a value for each aspect, then these partial results are aggregated, and this is how the GAM values for each location are determined. The M-GAM method includes the opinion of tourists in the evaluation of how important they consider the given aspect. As a result of the evaluation, it becomes clear which areas and objects have the highest geotouristic potential, so the development of their infrastructure may be recommended in the future.

Moreover, all the visited geosites of this research are included in the Hungarian National Geosite Inventory, which is currently under development. Several countries (e.g. Portugal, Spain, and Slovakia) have already created this type of geosite-cadastral to inventory geological, geomorphological, and geotouristic values. The Hungarian ProGEO Section prepared a datasheet, which is used to collect all basic information about geosites (Szepesi, 2022) – and we applied these outlines during our work in the High Gerecse Hills.

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