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COMPARATIVE ANALYSIS OF IMPACT AND VOLCANIC CRATER GEOSITES

IMPAKT ÉS VULKÁNI KRÁTER GEOHELYSZÍNEK ÖSSZEHASONLÍTÓ ELEMZÉSE

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Abstract

In the publication, the author compares the conservation and presentation solutions of 2–2 geohistorically recent, cataclysmic impact (Morasko, Steinheim) and volcanic crater (Kerið, Monte Nuovo) geosites examined as case studies. The topic is made relevant by the current earthquake events in the Campi Flegrei volcanic area in Italy, as well as the growing demand for geotourism. In situ field surveys and secondary data collection, which examined the components of the 24-item criteria framework used, revealed that the basic technical and logistical infrastructure was in place at all 4 sites studied, regardless of their origin. At the same time, significant differences are evident in the areas of visitor management, museum and commercial services: the impact craters examined during the research show a much more advanced operating model than the craters of volcanoes. Good practices that can be developed by continuing scientific work may be effectively applied in the future development of other international and even Hungarian geosites.

Keywords

impact crater, volcanic crater, geosite, geotourism, visitor infrastructure, nature conservation

Absztrakt

A publikációban a szerző 2–2 esettanulmányszerűen vizsgált földtörténeti újidejű, kataklizmikus keletkezésű impakt (Morasko, Steinheim) és vulkáni kráter (Kerið, Monte Nuovo) geohelyszín természetvédelmi és bemutatási megoldásait hasonlítja össze. A témát az olasz Campi Flegrei vulkáni terület aktuális földrengési eseményei, valamint a geoturizmus iránt növekvő igény teszi relevánssá. Az alkalmazott 24 elemes kritériumrendszer komponenseit vizsgáló in situ terepi bejárások és szekunder adatgyűjtések rávilágítottak, hogy az alapvető műszaki–logisztikai infrastruktúra mind a 4 vizsgált helyszínen biztosított, függetlenül a keletkezési eredettől. Ugyanakkor a látogatómenedzsment, valamint a múzeumi és kereskedelmi szolgáltatások terén jelentős eltérések mutatkoznak: a kutatás során vizsgált impakt kráterek jóval fejlettebb működtetési modellt mutatnak, mint a tűzhányók kráterei. A tudományos munka folytatásával kidolgozható jó gyakorlatok hatékonyan alkalmazhatók lehetnek más nemzetközi, sőt magyarországi geohelyszínek jövőbeli fejlesztésénél.

Kulcsszavak

impakt kráter, vulkáni kráter, geohelyszín, geoturizmus, látogatói infrastruktúra, természetvédelem

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INTRODUCTION

Scientific problem

On 31.08.2026, a 4.7 magnitude earthquake struck the Campi Flegrei volcanic field of the Italian Peninsula Volcanic Provinces [1]. The main and aftershocks caused personal injuries and significant building damage in the vicinity of Naples, in the Pozzuoli area [2]. The post-volcanic activity of the previous eruption centers of the caldera volcano, as well as the – unprofessional – designation "supervolcano" appearing in promotional literature, make the already popular southern Italian location a prominent geosite (geotope). Today's visitors do not want to see the dusty museum displays of igneous rocks and their minerals, but rather want to visit places close to nature, even extreme ones. The Campi Flegrei has now received considerable attention, even if this "promotion" is negative this time. However, visitor traffic may still increase in the medium term as a result.

In this regard, it is worth conducting a comparative analysis of the geosites of impact craters (meteorite craters, astroblemes) and volcanic craters (calderas) as a case study, examining their nature conservation aspects and operational solutions. Formations of volcanic origin are more numerous, and they can even serve as good practice in the case of the geosite development of the barely 200 meteorite craters on Earth. However, the opposite situation may also arise, since meteorite craters receive more attention due to their uniqueness, so the geosites of volcanic formations can "learn" from the solutions applied to formations of cosmic origin. The basis of the comparative analysis is the compliance with the criteria system introduced and published by the author in the case of the Morasko meteorite crater field in Poland [3].

The literature mainly deals with the topic from a tourism geography and nature conservation perspective [4]. In these, the cataclysmic origin of the objects is typically not the subject of the studies. From an organizational perspective, the UNESCO Global Geoparks Network, with its Geohazards working group [5], and the European Geoparks Network, with its "Volcanic Areas" Working Group [6], play a significant role. However, due to their large number and geopolitical reasons, their coverage does not cover all countries and geotopes.

The author of this article is working on the topic as a sub-research for his dissertation entitled *Impact of Extraterrestrial Objects and Management of its Consequences in Critical Infrastructures*, which is currently being developed in the research area of *Military environmental security* at the *Ludovika University of Public Service, Faculty of Military Sciences and Officer Training, Doctoral School of Military Engineering*, in the research topic of the *Relationship between the environment and security*.

Research hypotheses, goals, methods

Hypothesis 1 stated that we will encounter similar solutions in the nature protection and presentation of impact and volcanic craters of comparable geomorphological size range, formed by both recent geological and cataclysmic geological processes – as geotopes.

Hypothesis 2 stated that 2/3 of the applied criteria system assume identical values for the objects examined as case studies.

The specific aim of the research was the benchmarking of the geosites of the selected impact and volcanic formations. The general aim of the research was to contribute to later developments at the given sites, and in the case of further formations, to contribute to the future establishment of good practices.

The basis of the research method was the author's previous and current field visits to the impact and volcanic craters selected as case studies 2–2. As primary data collection, textual information was collected on site and photo documentation was prepared. For each object, this was supplemented, as necessary, by collecting secondary data from maps, professional databases and professional articles. This was followed by the determination of the relevant parameters of a total of 4 objects based on the 24-item criteria list previously established by the author. The sub-research then concluded with a comparative analysis of these.

CONDUCTED STUDIES AND PARTIAL CONCLUSIONS

Selection of the examinatiom sample

I included 2 meteorite craters formed during impact events and 2 volcanoes formed through volcanic processes in the study (Table 1). Of the impact craters, I chose the Polish Morasko and the German Steinheim astrobleme from the 3 closest to Hungary. Of the volcanoes, I analyzed 1–1 object each from Iceland (Kerið) and Italy (Monte Nuovo) from the 3 countries characterized by active volcanism in Europe.

Object name	Object country	Object type
Morasko	Poland	impact crater(s)
Steinheim	Germany	impact crater
Kerið	Iceland	impact crater
Monte Nuovo	Italy	impact crater

Table 1: 2–2 impact and volcanic craters included in the study, own editing, own compilation

An important criterion for the selection of the sample was that the formations of states whose economic and social development are significant in European and international comparison should become the subject of study. Thus, sufficient financial resources and cultural commitment are available for nature conservation, the preservation of such objects, and the "socialization" of their values through their presentation.

The presented image material is always divided into two parts. Firstly, it visualizes the characteristic geomorphological features of the formation itself. Secondly, the applied criteria system demonstrates 1-1 elements existing at the given location.

Presentation of the objects included in the study

Morasko (Poland) meteorite crater(s) - Morasko in Poland is a meteorite crater field. The crater field includes 7 impact craters. They were formed in the Holocene geological epoch, 5000 years ago. Their diameters are 20–90 m, and their depths are between 2.1–11.5 m. Administratively, it is part of Poznań. The geotope is named "Rezerwat Przyrody Meteoryt Morasko".

The in situ field visit and data collection took place on 02.07.2018. The status of the examined parameters is given in Table 2; its images are in Figures 1–2.

Figure 1: A lake-filled impact crater in the Morasko crater field in Poland, own photo

Figure 2: European fallow deer in the forested area of the Morasko crater field, own photo

Steinheim (Germany) meteorite crater - Steinheim in Germany is a twin crater. Impact crater. It was formed in the Miocene geological epoch (concurrent with the neighboring Ries), 15 million years ago. Its diameter is 3.8 km, and its depth is between 110 m. Administratively, it is part of Steinheim am Albuch. The geotope is named "Geopark Schwäbische Alb".

The in situ field visit and data collection took place on 27.06.2019. The status of the examined parameters is included in Table 2; its images are in Figures 3–4.

Figure 3: The Steinheim impact crater in Germany, own photo

Figure 4: Zoological finds in the Steinheim impact crater museum, own photo

Kerið (Iceland) volcanic crater - Kerið in Iceland is one of the volcanoes of the larger Grímsnes and the narrower Tjarnarhólar volcanic area. It is a collapsed cinder cone type volcano. It has been active since the Holocene geological epoch, its last eruption occurred 6500 years ago. There is a crater lake inside. Its diameter is 170–270 m, and its depth is 55 m. Administratively, it is part of Klausturholar. The geotope is named "Kerið Volcanic Crater".

The in situ field visit and data collection took place on 09.06.2023. The status of the examined parameters is included in Table 2; its images are in Figures 5–6.

Figure 5: The Kerið volcanic crater in Iceland, own photo

Figure 6: General information board about the Kerið volcanic crater, own photo

Monte Nuovo (Italy) volcanic crater - Monte Nuovo in Italy is one of the eruption centers of the Campi Flegrei volcanic field. It is a cinder cone type volcano. It has been active since the Holocene geological epoch, its last eruption (and formation) occurred in 1538. Its diameter is 420 m, its depth is 100–120 m. Administratively, it is part of Pozzuoli. The geotope is named "Oasi Naturalistica di Montenuovo".

The in situ field visit and data collection took place on 09.07.2026. The status of the examined parameters is included in Table 2; its images are in Figures 7–8.

Figure 7: The Monte Nuovo volcanic crater in Italy, own photo

Figure 8: Service building promoting the cultural maintenance of the Monte Nuovo volcanic crater, own photo

Analysis and evaluation of data sources

I characterized the operational solutions aimed at protecting and presenting natural values at the given geosite – according to the previously developed 24-element methodology – by their status. The first column of Table 2 contains their names. Columns 2–5 indicate their presence/absence ("yes" / "no").

Operational solutions aimed at protecting and presenting natural values at the geosite	Morasko	Steinheim	Kerið	Monte Nuovo
Legal designation	yes	yes	no	yes
Nature conservation guard service	no	yes	yes	no
Asphalted access road	yes	yes	yes	yes
Public transport	yes	yes	no	yes
Parking	yes	yes	yes	yes
Cultured toilets	yes	yes	no	no
Waste collectors	yes	yes	no	yes
Educational trail	yes	yes	no	yes
Educational trail stations	yes	yes	no	yes
Designated tourist routes	yes	yes	yes	yes
Viewpoints	yes	yes	yes	yes
General information boards	yes	yes	yes	yes
Information boards of specific attractions	yes	yes	no	yes
Geotope	yes	yes	yes	yes
Geological values	yes	yes	yes	yes
Hydrogeological values	yes	yes	yes	no
Zoological values	yes	yes	yes	no
Botanical values	yes	yes	no	yes
Historical memorial sites / cultural monuments	yes	yes	no	no
Cafe	no	yes	no	no

Gift shop	no	yes	no	no
Visitor centre	no	yes	no	no
Museum	no	yes	no	no
Crater trademark product	no	yes	no	no

Table 2: Status of operational solutions aimed at protecting and presenting natural values in the case of the 2–2 impact and volcanic craters included in the study, own compilation

The comparison based on the 24-item criteria shows that the development and scope of tourism and conservation services of the examined geosites show significant differences:

- **Outstanding development (Steinheim)** The Steinheim impact crater in Germany received a positive ("yes") rating in all (24/24) of the examined criteria. It is the only one with the highest level of visitor reception and geotourism infrastructure, including a visitor center, museum, cafeteria, souvenir shop and branded products.
- **Strong basic services (Morasko)** Morasko in Poland also has a high level of development (19/24), has excellent infrastructure (toilets, waste collection, educational trail, information boards, cultural and historical monuments). However, specifically commercial and museum-type services (cafeteria, souvenir shop, visitor center) are still missing.
- **Common basic infrastructure** All 4 geosites have in common that the basic technical-logistical conditions (paved access road, parking lot), accessibility (designated tourist trails, viewpoints), basic information (general signs) and the geotopic/geological value itself are provided without exception.
- **Deficiencies in volcanic craters (Kerið and Monte Nuovo)** The 2 volcanic craters present a more incomplete picture from an infrastructure perspective. In the case of Kerið in Iceland (since its area is privately owned), there is no formal legal designation, public transport, toilets and a network of nature trails (although it has a ranger service). Monte Nuovo in Italy has legal protection and nature trails, but it lacks a nature conservation ranger service, toilets and a more complex visitor infrastructure.
- **Summary** While basic accessibility and geological presentation are provided everywhere, in the studied sample, impact craters (especially Steinheim) show a much more advanced operating model than the studied volcanic craters in terms of geotourism experience complexity. Furthermore, the structural divergence between impact and volcanic geosites can be attributed to differing institutional and financial management models. In the case of Kerið, private landownership enables direct ticket revenue generation, yet this income is predominantly channeled into physical site maintenance and safety rather than institutional geotourism infrastructure (such as educational centers or dedicated museum facilities). Conversely, sites integrated into regional geopark structures or municipal management frameworks (e.g., Steinheim and Morasko) demonstrate a higher capacity for long-term institutional funding, enabling the establishment of standardized educational networks, official protection status, and comprehensive site interpretation. This highlights that formal environmental protection does not automatically guarantee high-level visitor infrastructure; rather, integrated governance models are critical for multi-tiered geosite development.

CONCLUSION

Summary conclusions

The benchmarking analysis of the 4 objects (the Morasko impact craters in Poland and the Steinheim impact craters in Germany, and the Kerið volcanic craters in Iceland and the Monte Nuovo volcanic craters in Italy) based on a 24-item criteria system shed light on the patterns of nature conservation and operation practices of cataclysmic geotopes.

Hypothesis 1 was partially confirmed. Confirmed elements: There are indeed uniform solutions in the field of basic technical, logistical and presentation infrastructure. All 4 sites have an asphalt access road and parking lot, designated tourist trails, viewpoints and general information boards, and each site is a well-known geotope where the presentation of geoscience values is ensured. Different elements: However, the similarity stops at the level of basic infrastructure. In terms of the presence of a nature conservation guard service, the nature trail network, the toilet and waste collection capacities, and the complex visitor reception and museum facilities, the case study already shows significant structural differences between the 2 formation types.

Hypothesis 2 was not confirmed. The 2/3 (66.7%) expectation assumed that all 4 examined objects would take the same value ("yes" or "no") for at least 16 of the 24 examination aspects. The analysis showed that only 7 criteria (29.2%) of the 24-element matrix achieved complete agreement at all 4 geosites (access road, parking lot, tourist trails, viewpoints, general information boards, geotopic status, geological values). For the remaining 17 aspects (70.8%), the individual geosites showed different statuses, as the development levels were significantly dispersed: Steinheim 100% (24/24), Morasko 79.2% (19/24), Monte Nuovo 54.2% (13/24), while Kerið 41.7% (10/24).

The results show that it is not the more numerous and well-known volcanic craters that have a more developed nature conservation and tourism infrastructure. Based on the sample examined, it is the more unique impact craters (especially Steinheim and Morasko) that show a more complex operating model and a higher level of geotourism development.

The refutation of Hypothesis 2 underscores the structural heterogeneity of European geotopes regardless of their genetic classification. While geomorphological scale and cataclysmic origin are comparable, management intensity is governed primarily by local socio-economic drivers, accessibility to regional tourism flows, and administrative priorities. The surprisingly advanced status of impact craters reveals that their spatial rarity acts as a catalyst for targeted scientific interest and municipal branding, resulting in superior educational and museum facilities. In contrast, volcanic craters – frequently treated as conventional landscape elements or mass-tourism transit points – often lack comprehensive interpretation frameworks unless strictly embedded within active Geopark management systems. Consequently, volcanic geosites require a strategic shift toward integrated visitor management tools, structured zoning, and interactive site interpretation to fully leverage their educational potential.

Further possible directions of the research, practical applicability of the results

A further possible direction of the research is to expand the number of the study sample by significantly increasing the current – case study – number of 2-2 objects. In addition to European destinations, craters from other continents can be included in the sampling and analysis. Furthermore, we should not forget about the solutions applied to the ruin volcanoes of the Hungarian volcanic areas that are of particular importance from a touristic

and geographical point of view (e.g. Bakony–Balaton Geopark / Bakony–Balaton-felvidéki volcanic area / Hegyestű).

The practical applicability of the results assumes that we can gain a much more complete picture of the solutions for the preservation of the 2 types of formations. The data that can be extracted can serve as good practice for tourism developments and the implementation of nature and environmental protection goals in the case of additional geotopes in the given country or in other countries. They can also point out possible elements of the formations already included in the study that need to be developed.

Refining the applied criteria system would enable even more precise data collection and more sophisticated analysis. Accordingly, it is worth moving in this direction in future research. Methodologically, future iterations of this study should transition from a binary ("yes" / "no") evaluation matrix toward a weighted, multi-criteria analysis. Assigning quantitative weights to critical parameters – such as carrying capacity, environmental vulnerability, and digital interpretation tools (e.g., QR-code trails, augmented reality) – will yield a more nuanced geosite assessment index. Ultimately, this benchmark system serves as a practical decision-support tool for protected area managers, land-use planners, and geotourism policy makers aiming to balance geoconservation with sustainable visitor capacity.

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