



Mud Volcanoes of Azerbaijan as a Geological Heritage: Geoconservation, Geotourism, and the Prerequisites for the Creation of a Geopark

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Abstract. The mud volcanoes of eastern Azerbaijan and the adjacent South Caspian Basin form one of the most dense and morphologically diverse mud volcanic provinces in the world. This paper summarizes data on their distribution, typology, scientific and educational value, the current legal protection system, and the potential for geotourism development. Ayrantoken, Arzani, Gelenderakhtarma, and the island volcano Garasu are examined separately as examples of various morphological and spatial types. The analysis shows that the combination of active fluid manifestations, varied topography, and connections to deep petroleum systems determines the high potential of mud volcanoes as geological heritage sites. The state nature reserve, national regulation of geological parks, and emerging tourism infrastructure provide the foundation for the development of a geopark initiative. However, preparing a potential nomination for the UNESCO Global Geoparks program requires defining a single territory, establishing a specialized management body, developing a long-term geoconservation and security plan, and documenting the participation of local communities. The study concludes that Azerbaijan possesses the essential geological and institutional prerequisites for a future geopark, although systematic geosite assessment, integrated management, and community participation remain necessary before a UNESCO Global Geoparks application can be considered.

Keywords: mud volcanism; geological heritage; geoconservation; geosites; geotourism; South Caspian Basin; UNESCO Global Geoparks

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1. Introduction

Mud volcanism is a form of sedimentary volcanism in which overcompacted and fluid-saturated sediments, water, and gases migrate to the surface through zones of increased permeability (Aliyev et al., 2015; Baldermann et al., 2020; Baloglanov, 2023; Bayramova et al. 2023; Mazzini & Etiope 2017). The depth of fluid sources and the structure of feeder channels vary between individual systems and are estimated based on geochemical, geophysical, and structural-geological data. Breccias brought to the surface and associated fluids provide indirect information about deep sedimentary complexes, petroleum systems, and degassing processes (Aliyev, 1992).

The global number of mud volcanoes remains uncertain and depends on the terminology used, the scale of mapping, and the completeness of the accounting of underwater manifestations (Baloglanov, Abbasov, & Akhundov, 2018). Different inventories may account for large volcanic edifices, individual gryphons, salses, and deep-sea structures differently.

According to the inventory data used in this work, 353 mud volcanoes have been recorded in eastern Azerbaijan and the adjacent waters of the South Caspian Sea, including 199 land-based and 154 offshore objects (Aliyev et al., 2015; Baloglanov, Abbasov, & Akhundov, 2018). Their high concentration and morphological diversity determine the special position of the region in the system of global mud volcanism (Fig 1).

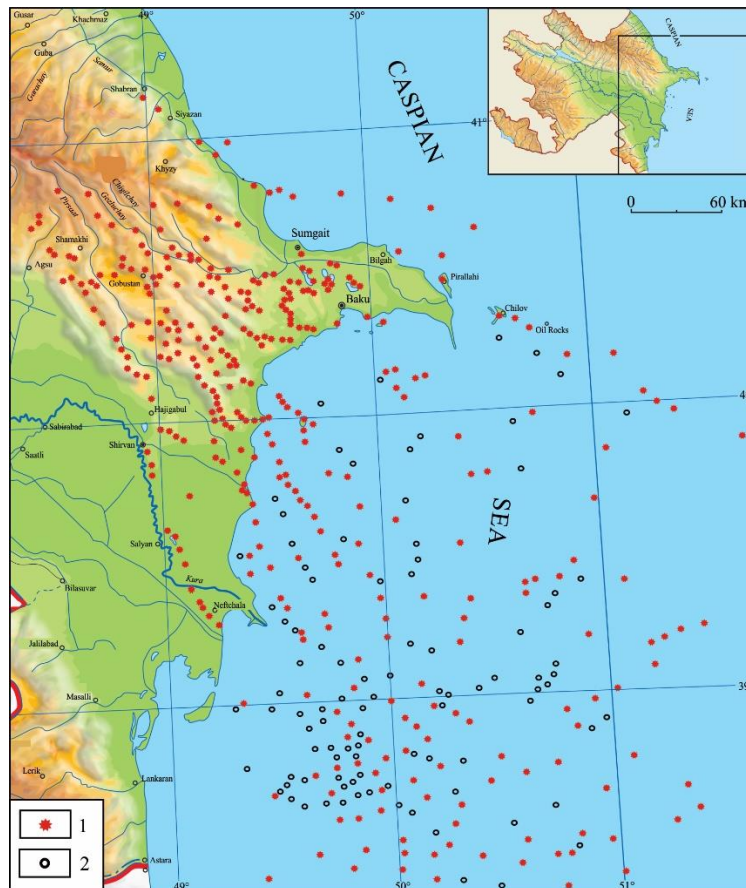


Figure 1. Map of the location of mud volcanoes in Azerbaijan.
Mud volcanoes: 1 – identified; 2 – supposed [3].

Mud volcanoes of Azerbaijan are of interest for the study of petroleum systems, deep fluid migration, methane emission and transformation, microbiological processes, as well as the links between mud volcanic activity, tectonics, and seismicity (Baloglanov et al., 2017; Etiope et al., 2004; Imbert et al., 2019; Liu et al., 2024; Mellors et al., 2007). Their landscape appearance is formed by erosional relief, mud cones, salses, gryphons, and areas of active fluid release. Historical eruptions, including cases of gas ignition, simultaneously increase the scientific significance of the sites and necessitate the consideration of natural risks (Aliyev et al., 2015; Aliyev, Guliyev, & Belov, 2002)

The concept of geological heritage has received significant development thanks to international and national initiatives in the field of geoconservation. The UNESCO Global Geoparks Programme, established in 2015, integrates the conservation of geological heritage with education, sustainable development,



geotourism, and local community participation (Aliyev et al., 2024). Lokbatan has been included by Azerbaijan on the UNESCO World Heritage Tentative List since 30 September 1998 (UNESCO 1998). This designation is under the World Heritage Convention and does not constitute a nomination or recognition under the UNESCO Global Geoparks Programme.

Although numerous studies have examined the geology, geochemistry, and eruptive activity of Azerbaijan's mud volcanoes, relatively few have evaluated them comprehensively from the perspective of geological heritage, geoconservation, geotourism, and geopark development. This review aims to bridge that gap by integrating these aspects within a single analytical framework.

The aim of this study is to assess the geological legacy of mud volcanic landscapes in Azerbaijan and the prerequisites for their development within the framework of the Geopark model. To achieve this goal, data on the distribution and typology of mud volcanoes are summarized, four representative sites are examined, and the current legal protection system, tourism infrastructure, and key management constraints are analyzed. Special attention is given to delineating the value of individual geosites and the requirements for the UNESCO Global Geopark.

2. Materials and methods

This work is presented in the format of a narrative review. The source base consists of scientific articles, monographs, and informational materials presented in the bibliography. The sources were selected based on their relevance to the main research areas: the distribution and classification of mud volcanoes, their geological structure and activity, geological heritage, legal protection, geotourism, and geopark management.

The analysis was conducted at two levels. At the individual site level, scientific, educational, aesthetic, and tourist value, accessibility, natural hazards, and the current protection regime were considered. At the territorial level, the prerequisites for establishing a geopark were assessed, including the legal and institutional framework, geoconservation opportunities, tourism infrastructure, and local community participation. The analysis was qualitative in nature and did not involve a rating system for the sites.

Instead, the assessment relied on a comparative synthesis of published geological, environmental, legal, and tourism-related information to identify the strengths, limitations, and development potential of representative mud volcano sites.

3. Global distribution and morphological diversity of mud volcanoes

3.1. Global distribution

According to the inventory (Baloglanov, Abbasov, & Akhundov, 2018), which includes terrestrial and underwater manifestations, 2,508 objects were recorded in 42 geographic regions. Their main areas of distribution are confined to the Alpine-Himalayan, Pacific, and Central Asian orogenic belts, as well as the deep-water parts of the Caspian, Black, and Mediterranean seas. Of the total number of recorded objects, 1,107 are terrestrial, and 1,401 are underwater mud volcanic structures. These values characterize a specific inventory base and are not considered a final estimate of their global number.

3.2. Morphological diversity of mud volcanoes in Azerbaijan

Mud volcanoes in Azerbaijan include terrestrial, island, and underwater forms. Based on their general morphology, cone-shaped, dome-shaped, ridge-shaped, and plateau-shaped structures are distinguished; shield-shaped, caldera-shaped, and other varieties are distinguished based on the structure of the crater region. Modern activity is manifested by periodic eruptions, the activity of gryphons and salses, as well as relatively weak fluid manifestations (Aliyev et al., 2015). The combination of various morphological types, activity regimes, and fluid composition makes the region an important natural platform for the comparative study of mud volcanic processes (Fig. 2) (Aliyev et al, 2024; Odonne et al., 2020; Odonne et al., 2021)



Figure 2. Examples of morphological types of mud volcanoes in Azerbaijan: a) Shorbulag, b) Sengi-Mugan, c) Toraghay, d) Durovdagh.

4. The value of Azerbaijan's mud volcanoes as geological heritage sites

4.1. Key components of geological heritage value

Based on the approach outlined in Section 2, the value of mud volcanoes is considered across scientific, educational, aesthetic, and cultural-historical dimensions. Available data indicate their high potential as geological heritage sites. However, the lack of a unified quantitative assessment limits the ability to compare sites and prioritize conservation.

Scientific significance: Breccia, water, and gases brought to the surface contain information about sedimentary complexes and fluid systems intersected by feeder channels. Their study allows us to investigate hydrocarbon migration, the origin and transformation of methane, interactions in the water-rock-gas system, the structure of mud volcanic channels, and the relationship of volcanic activity to regional tectonics (Etiope et al., 2004; Liu et al., 2024; Mazzini & Etiope 2017).

Educational value: Gryphons, salses, breccia blankets, and erosional features can be used for fieldwork in geology, geochemistry, and environmental science. Educational routes should consider gas release, surface instability, conservation regimes, and permissible recreational loads (Aliyev et al., 2024; Kopf et al., 2010; Kopf et al., 2009).

Aesthetic qualities: The contrast between the mud volcanic landforms and the surrounding semi-desert landscape determines the high visual expressiveness of the objects. Their aesthetic potential is due to the diversity of forms, the openness of geological processes for observation, and the possibility of panoramic perception of the landscape.



Cultural and historical value: Mud volcanoes are mentioned in ancient Greek, Roman, and medieval Arabic sources (Aliyev et al., 2015). Their cultural significance is also reflected in local toponymy, legends, and traditional perceptions of the landscape. One example is the name Lokbatan, the origin of which is associated with local historical and cultural beliefs (UNESCO, 1998).

4.2. Legal protection and international recognition

Legal protection of Azerbaijan's mud volcanoes is developing at the national level and is complemented by initiatives aimed at their international recognition.

National legal protection: In 1982, Lokbatan, Ayrantoken, Boyuk Kenizadagh and Dashgil were included in the list of geological sites taken under state protection (Aliyev et al., 2024). By the Decree of the President of the Republic of Azerbaijan No. 2315 dated August 15, 2007, the State Nature Reserve of the Baku and Absheron Peninsula Mud Volcanoes Group was established. The reserve, with an area of 12,322.84 hectares, ensures the protection of 43 mud volcanoes, including Toraghay, characterized as one of the largest mud volcanoes in the world. The main objectives of the reserve are to limit anthropogenic impact, prevent development, and ensure the protection of potentially hazardous areas.

International recognition: On 30 September 1998, Lokbatan was inscribed by Azerbaijan on the UNESCO World Heritage Tentative List as a natural property under criteria (vii), (viii) and (ix) (UNESCO, 1998). This status reflects the State's intention to consider the property as a candidate for future nomination, but does not imply recognition of its outstanding universal value by the World Heritage Committee.

Current initiatives: In 2020, the Ministry of Ecology and Natural Resources, together with local and international experts, began studying areas promising for the creation of geoparks. That same year, the General Regulation on Geoparks was approved, defining the legal and organizational framework for their creation and management in Azerbaijan. This document forms the national regulatory framework, but preparing an application for the UNESCO Global Geoparks program requires independent compliance with international requirements.

5. Representative objects

To characterize the diversity of mud volcanic heritage, four sites are considered: Ayrantoken, Arzani, and Gelenderakhtarma in the Shamakhi-Gobustan Province, as well as the island volcano Garasu in the Baku Archipelago. They represent different morphological and spatial types and are characterized by well-documented fluid manifestations. The selection of sites is illustrative and does not constitute a definitive ranking of Azerbaijan's mud volcanoes.

The Ayrantoken mud volcano is located at 39°59'21.67" N, 49°18'38.87" E, approximately 65 km southwest of Baku. It is an active plateau-like structure with a relative height of about 190 m. The volcanic edifice includes a breccia field with an area of 805 hectares and a volume of up to 500 million m³. The length of individual breccia flows reaches 1.5 km, and faults – 800 m. Oil-showing gryphons and mud cones 5-10 m high are developed on the territory of the volcano (Fig. 3). Eruptions during periods of high activity could be accompanied by gas ignition and the formation of flame columns up to 500 m high (Aliyev et al., 2015).

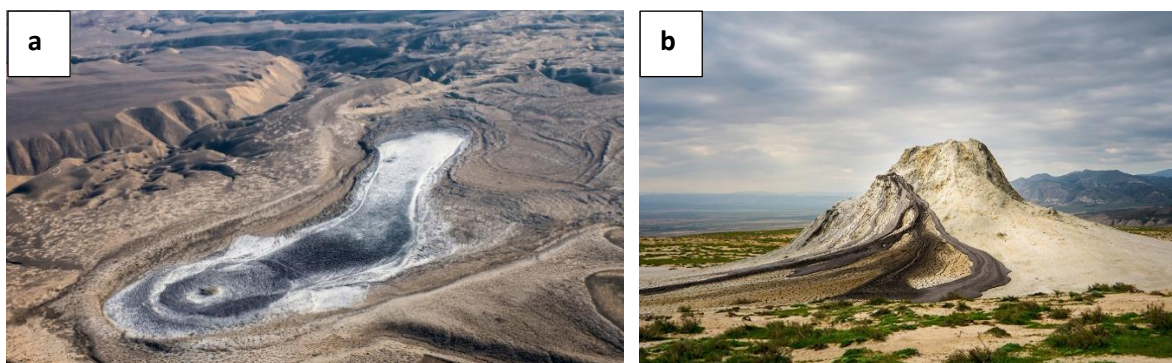


Figure 3. Ayrantoken mud volcano: a) aerial photograph from a helicopter, b) an active mud cone (sopka) on the territory of the volcano.

The scale of the breccia field, active oil and gas manifestations, and traces of past eruptions determine the scientific and educational value of Ayrantoken. Its tourist use requires taking into account the security regime, gas danger, surface stability, the condition of access roads and the possibility of organizing controlled routes.

The Arzani mud volcano is located at 40°10'49.41" N, 49°11'24.34" E, approximately 63 km southwest of Baku and 20 km northwest of the village of Gobustan. It is a plateau-like elevation with an area of approximately 50 hectares. The volcano's western slope faces the Toragay Plain, and to the north, it is bordered by Mount Galandarakhtarma and the Shirgobu River. Its geological structure includes deposits of the productive strata and the Upper Maykopian.

Three distinct microform distribution areas are identified within Arzani. The first area, over 4.5 hectares in area, contains over 30 mudflats and griffins, including oil-producing forms and a large mudflat with a hardened bitumen cover. The second area, approximately 1 hectare in area, is located approximately 300 meters to the southeast and contains approximately 15 griffins. The third area, approximately 470 meters to the east, is an eruptive field covering 16.5 hectares (Fig. 4) (Aliyev et al., 2015).

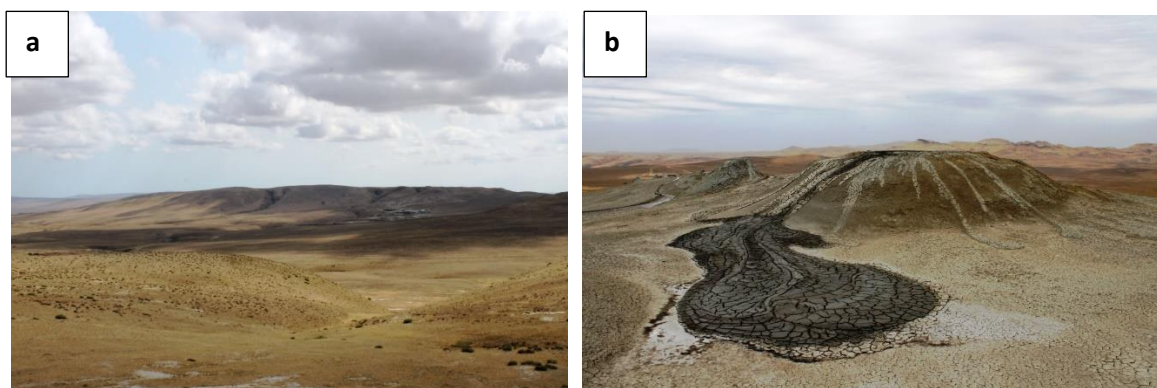


Figure 4. Arzani mud volcano: a) general view, b) mud cone.

The high concentration and diversity of microforms define Arzani's scientific and educational potential. Assessing its tourism potential requires data on the safety of oil and gas seeps, surface stability, accessibility, and acceptable visitor numbers.

The Gelenderakhtarma mud volcano is located at coordinates 40°15'3.31" N, 49°14'45.52" E and is confined to the eastern pericline of the Umbakinskaya anticline, composed of Miocene deposits. The structure, elongated in the latitudinal direction, has a relative height of about 160 m and a steep eastern slope. The crater field, which extends for more than 1 km, includes numerous active gryphons, saline lakes,

and mud cones more than 15 m high. The area of the breccia cover reaches 562 hectares, and its thickness, according to drilling data, is up to 30 m (Fig. 5) (Aliyev et al., 2015).



Figure 5. General view of the Gelenderakhtarma mud volcano.

The large size of the volcanic edifice and the high density of active microforms determine the scientific, educational, and aesthetic value of the site. Its potential for tourism use should be assessed taking into account accessibility, natural risks, and the protection regime.

Garasu is located at 39°50'7.16" N, 49°31'55.73" E and is a large island mud volcano in the Baku Archipelago. It is located in the Hamamdagh–Dashly Island anticline zone. The island is approximately 1.2 km long, up to 0.6 km wide, and reaches a height of 14 m in its northern part. The relief includes active gryphons, saline lakes, areas of gas, water, and mud emission, cracks, and coastal deformations (Fig. 6).

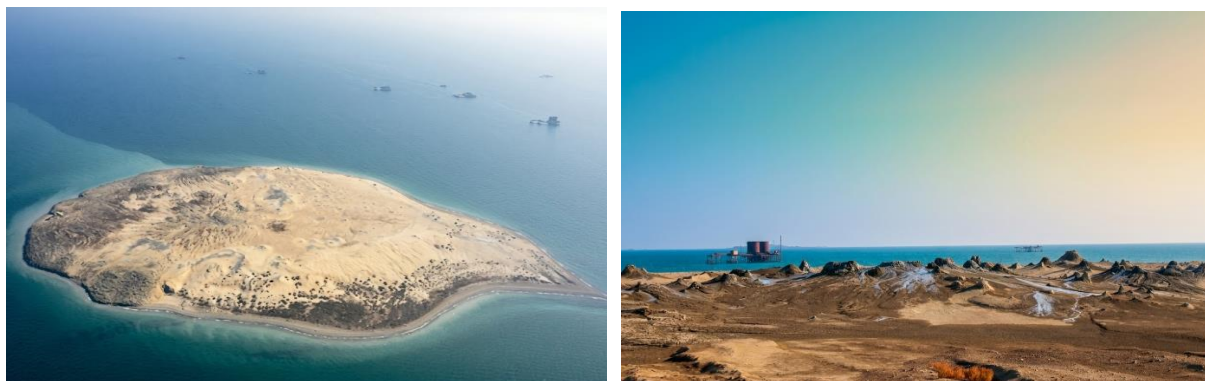


Figure 6. Garasu mud volcano: a) aerial photograph from a helicopter, b) the crater field of the volcano.

The 1977 eruption, accompanied by gas ignition, lasted for more than two days and resulted in the release of over 1.5 million m³ of breccia. The 1993 eruption did not involve intense combustion or massive breccia release, but was accompanied by surface subsidence, the formation of sinkholes, and the development of fissures. These events reflect the volcanic variability (Aliyev et al., 2015).

Garasu's island location, coastal instability, fracture formation, and constant fluid release enhance its scientific value but limit public access. Until a marine access and risk management plan is developed, the site should be used primarily for remote monitoring, specialized scientific expeditions, and digital interpretation.



6. Prerequisites for the development of the geopark

Azerbaijan has established important legal, environmental, and institutional foundations that support the future development of geoparks. These include the activities of the State Nature Reserve, national regulation of geological parks, and the creation of specialized tourism infrastructure. The reserve's experience can be used to organize geoconservation and monitoring of future geopark territories. However, preparing an international nomination requires defining uniform boundaries, establishing a specialized governing body, developing an integrated development plan, and establishing a mechanism for the participation of municipalities, local communities, and entrepreneurs.

A UNESCO Global Geopark should integrate geological heritage of international significance with long-term management, geoconservation, education, sustainable development, geotourism, and local community participation (Aliyev et al., 2024). Available data allow us to identify certain prerequisites for meeting these requirements, but do not confirm the site's full readiness.

The scientific significance of Azerbaijan's mud volcanoes is determined by their high concentration, morphological diversity, and the geological conditions of the South Caspian Basin, whose sedimentary cover exceeds 30 km (Aliyev et al., 2015). Designating the area as a state nature reserve ensures its legal protection and creates a reliable basis for regular monitoring. At the same time, establishing a geopark requires a unified territory, a specialized management system, a long-term development plan, and documented participation of local communities.

Preparing a geopark designation requires addressing several interrelated issues. Key constraints include the fragmentation of protected areas, the lack of a comparative geosite inventory, surface instability, gas emission, fracturing, subsidence, erosion of breccia blankets, and unregulated off-road vehicle traffic. Additional challenges include the proximity of individual sites to development zones, limited accessibility of island volcanoes, and insufficient community engagement. For the most visited sites, plans for safety, security, and recreational load management are required. Addressing these constraints should be regarded as a priority before initiating an application to the UNESCO Global Geoparks Programme.

At the same time, conditions exist that facilitate the development of a geopark initiative. The state nature reserve forms the institutional basis for geoconservation, and the existing tourist infrastructure increases accessibility to individual sites. Their distinctive geomorphology provides an opportunity to develop a unique geotourism identity that differs from traditional mountain- and cave-based geoparks.

7. Geotourism and sustainable development

Specialized geotourism infrastructure related to mud volcanoes is currently under development. Geotourism provides an opportunity to promote geological heritage while supporting environmental education, regional economic development, and public awareness of geoconservation. A key feature of this development is the availability of tourist infrastructure, including information and exhibition spaces, observation platforms, and visitor services. Tour programs often combine visits to mud volcanoes with the Gobustan rock art and other archaeological and cultural sites. Such integrated routes increase the educational value of excursions and encourage visitors to explore both the geological and cultural heritage of the region. The proximity of some volcanoes to Baku creates opportunities for one-day itineraries, while more distant sites can be included in specialized multi-day programs. However, a unified geotourism network encompassing these sites has not yet been established.

Interpretation of mud volcanoes for visitors should be based on safe observation of passive fluid manifestations, landforms, and geological processes in the South Caspian Basin. Eruptions are unpredictable and may be accompanied by the release of breccia, gases, and ignition, so they should not be considered a tourist product. Consequently, visitor management should prioritize safety, environmental protection, and scientifically guided interpretation rather than direct observation of hazardous volcanic



activity. The use of mud volcanic material for health purposes also requires separate mineralogical, geochemical, microbiological, toxicological, and clinical studies and is not assessed in this paper.

Geopark development can contribute to local economic diversification, employment, and support for small businesses. To achieve this, tourist flows must be regulated with due regard for environmental constraints, and local communities must participate in the provision of services and the distribution of economic benefits. The effectiveness of this approach can be assessed by the level of local employment, the participation of local providers, the condition of geosites, the satisfaction of residents and visitors, and the number of protection violations.

8. Practical priorities

1. Complete an inventory of mud volcanic geosites and conduct a comparative qualitative assessment.
2. Define the boundaries of the proposed geopark area and develop a specialized management system.
3. Develop geoconservation, monitoring, and safety plans for the most active and visited sites.
4. Develop a unified system of educational routes, information materials, and guide training.
5. Ensure the participation of local communities, municipalities, and entrepreneurs in the planning and implementation of the geopark initiative.
6. Prepare the official international application after a sustainable management system has been established and the key requirements of the UNESCO Global Geoparks program have been met.

9. Conclusions

The mud volcanic landscapes of Azerbaijan form a diverse complex of geological heritage sites. Their scientific value stems from active fluid manifestations, the morphology of volcanic edifices, and the opportunity to study deep sedimentary and petroleum systems. The accessibility of some sites and the distinctiveness of their topography create additional opportunities for field education and geotourism.

A state nature reserve, national regulation of geological parks, and developing tourism infrastructure form the foundation for the geopark initiative. The inclusion of Lokbatan on the UNESCO World Heritage Tentative List demonstrates the international interest in the country's mud volcanic heritage. However, existing forms of protection and recognition do not replace the specialized management system of a UNESCO Global Geopark.

Ayrantoken, Arzani, Gelenderakhtarma, and Garasu exhibit differences in morphology, activity patterns, accessibility, and natural risks. Further development of the geopark initiative should be based on an inventory of geosites, the definition of a unified territory, the development of geoconservation and safety plans, and the participation of local communities. Achieving these objectives will allow for the integration of geological heritage protection, scientific research, education, and sustainable geotourism within a single strategy. This review is based on published scientific literature and official sources and does not include original field investigations or quantitative geosite assessment. Future research should apply standardized geosite evaluation methods, GIS-based spatial analysis, and field-based investigations to support evidence-based geopark planning and sustainable management.

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