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A framework for the establishment of an interpretive center at the Lake Bosumtwi Impact Crater, Ghana: a hub for geoscience education and social geosciences

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Abstract

The Lake Bosumtwi Impact Crater in Ghana, approximately 1.07 million years old and designated as an IUGS Geological Heritage Site, holds significant geological, educational, cultural, aesthetic, and economic importance. Historically, its potential for education and community involvement has been underutilized. This study developed a framework for creating an interpretive center for the Lake Bosumtwi Impact Crater by conducting a systematic literature review and comparative analysis of Geopark Ries (Germany), Vredefort Dome (South Africa), and Ngorongoro Conservation Area (Tanzania), along with local knowledge gathered through field visits. Our framework offers a model that combines geoethics, geoscience education, and social geosciences. It is built on three pillars: 1) immersive geoscience education to improve public geoliteracy; 2) implementing geoethics through community-led governance and ethical geotourism; and 3) advancing social geoscience through participatory research and sustainable local initiatives. We conclude that this integrated approach can transform the Lake Bosumtwi Impact Crater from a site focused on scientific research to a hub for inclusive knowledge sharing and sustainable development. It can also serve as a replicable model for connecting

geological heritage with community well-being and addressing issues of geoscientific marginalization.

Keywords: Geoethics, Social geosciences, Geoscience education, Geoheritage, Lake Bosumtwi Impact Crater.

1. Introduction

Impact craters are key geologic features for understanding planetary science and Earth's history (Grieve, 1990; Schmieder and Kring, 2020). The Lake Bosumtwi Impact Crater in Ghana (Figures 1-3) is a prime example of such a structure. Formed approximately 1.07 million years ago (Koeberl et al., 1998), it is young, well preserved, and has a complex structure with a central lake. This makes it a focal point for international research, including a major International Continental Scientific Drilling Program (ICDP) project (Koeberl et al., 2007). The designation of the lake's watershed as a UNESCO World Biosphere Reserve (Abreu et al., 2016; UNESCO, 2016a) and its recent designation as an International Union of Geological Sciences (IUGS) Geological Heritage Site (Koeberl et al., 2024) confirms its global significance.

Beyond its geological, scientific, and educational merits, the crater and its lake are deeply interwoven with the cultural and spiritual heritage of the Ashanti people of Ghana, serving as a sacred landscape (Boamah and Koeberl, 2007). This intersection of science and culture presents a critical opportunity to advance geoethics, which has been defined as the analysis of the ethical, social, and cultural implications of geoscience practice (Peppoloni and Di Capua, 2012, 2021, 2022). Despite this potential, the Lake Bosumtwi Impact Crater has historically served as a site for scientific extraction, offering limited local educational or economic benefits. This highlights a gap in social geoscience which is the integration of sustainability and societal concepts into Earth sciences (Stewart and Gill, 2017).

A review of past initiatives revealed a history of unsustained projects and initiatives (e.g., GhanaWeb, 2003; Boamah and Koeberl, 2007; Mohammed, 2014, 2018; Abreu et al., 2016; UNESCO, 2023). These efforts, predominantly small-scale ecotourism schemes, have largely failed to achieve long-term sustainability due to multiple interrelated constraints: i) the adoption of top-down planning approaches

that excluded substantive community participation, thereby undermining local ownership and stewardship; ii) inconsistent financial commitment, whereby initial capital investments were not accompanied by sustained operational funding; iii) inadequate integration of cultural and scientific narratives, as many projects where efforts are often focused solely on either science or tourism, failing to integrate the cultural, educational, and ethical dimensions into a cohesive, self-sustaining model, and iv) the absence of a robust national policy framework specifically dedicated to geoheritage conservation and management has left such sites vulnerable and unsupported. This has resulted in a landscape where global scientific value contrasts sharply with local underdevelopment and disengagement, creating an ethical need for a new model centred on inclusivity and shared benefit.

An interpretive center (Brody, 2015), which may also be known as a visitor center, nature center, or discovery center, is a facility designed to help visitors understand and appreciate the significance of a particular place, for its natural, cultural, historical, or geological heritage. This is achieved through a core philosophy of interpretation, which is carried out through storytelling (e.g., Matias et al., 2019; Teixeira et al., 2023), immersive experiences, and interactive exhibits(e.g., Bouziat et al., 2020; Bonali et al., 2021; Horota et al., 2022; Ajani and Ramaila, 2025; Cook et al., 2025) to provoke curiosity, convey meaning, and foster emotional and intellectual connection to the subject. Interpretive centers play a crucial role in enhancing conservation, promoting education, driving sustainable tourism, empowering communities and fostering a sense of place by helping both visitors and locals understand what is unique and valuable about a specific location, thus strengthening regional identity (e.g., Stewart et al., 1998; Stronza and Gordillo, 2008; Ballantyne et al., 2011). For the Lake Bosumtwi Impact Crater, an interpretive center can help to:

- Preserve a rare natural wonder by educating the public on impact crater formation, shock metamorphism, meteorites, tektites, etc, thereby safeguarding this unique geoheritage.
- Advance scientific knowledge by showcasing ongoing research and attracting global geoscientists, positioning Ghana as a location for planetary science.
- Enhance STEM education with interactive exhibits on geology, astronomy, and ecology, partnering with schools for field trips and workshops to inspire the next generation of Ghanaian scientists.
- Safeguard the cultural heritage of a people by documenting and celebrating oral histories, myths, and sacred practices, fostering cultural pride.
- Revive indigenous knowledge by collaborating with the indigenous people and researchers to archive Traditional Ecological Knowledge (TEK), including sustainable fishing practices and the uses of medicinal plants, ensuring intergenerational transfer.

- Protect a fragile ecosystem by promoting conservation of the lake's endemic species and unique rainforest biodiversity. The center could educate on sustainable practices, fund reforestation to combat rim erosion, and monitor water quality through citizen science.
- Foster economic empowerment by creating direct employment (e.g., guides, artisans, center staff) and stimulating indirect jobs (e.g., accommodation, transport).
- Promote sustainable geotourism by establishing the site as a flagship geotourism destination.
- Enhance global recognition by strengthening the case for a future UNESCO Geopark designation and fostering international partnerships with organizations like the International Geoscience Programme (IGCP) and others.
- Build community resilience by uniting stakeholders such as local chiefs, scientists, NGOs, and government agencies in a collaborative governance model. This approach empowers marginalized groups, including women and youth, thereby reducing rural-urban migration.

Based on these insights, the primary objective of this work is to present a comprehensive and relevant framework for the establishment of an interpretive center for the Lake Bosumtwi Impact Crater. This can be achieved by analysing the site's current status, learning from comparable African initiatives, and synthesizing a model that integrates geoethics, geoscience education, and social geoscience. The specific aims are; to conceptualize a center that enhances public geoliteracy and engagement with Earth sciences through immersive, interactive educational exhibits and programs, to promote the principles of geoethics in geo-resource management and decision-making, to foster a sense of responsibility towards the site, and to empower local communities through participatory research initiatives, capacity building, and the co-development of sustainable geotourism enterprises that provide tangible socio-economic benefits.

2. Methods

To develop a robust framework for the Bosumtwi interpretive center, this study employed a comprehensive literature review methodology supplemented by comparative case study analysis. The research methodology was structured as follows:

i) A systematic review of peer-reviewed literature, government reports, and international case studies was conducted across four critical domains:
   - Status of Lake Bosumtwi Impact Crater: Analysis of existing literature on the

crater's geological significance, conservation status, cultural importance, and existing educational and tourism infrastructure gaps.

- Geoethics and community engagement: Examining frameworks for ethical practices and community participation in geoscience initiatives, with particular attention to models applicable to sacred landscapes.
- Geoscience education: Investigating best practices in informal, place-based geoscience education and public engagement strategies, especially in the Global South contexts.
- Geotourism and Geoheritage Management: Review models for sustainable geotourism development and geoheritage conservation, focusing on community-benefit approaches.

ii) Comparative case study analysis of successful geoheritage initiatives to extract transferable lessons:

- Geopark Ries[1], Germany: Analysis of its approach to balancing effective scientific communication and community integration. This approach demonstrates that a geoheritage site can function as the central pillar for regional development, fostering local pride and ensuring that economic benefits are widely distributed throughout the community, thereby securing long-term public support for conservation goals.
- Vredefort Dome[2], South Africa: Analysis of its approach to translating complex geological science into accessible public education and establishing a geotourism economy within a World Heritage framework in a developing world context.
- Ngorongoro Conservation Area[3], Tanzania: Examination of its integrated governance model that balances conservation objectives with the rights and cultural practices of indigenous communities.

iii) Local knowledge and experience from field visits: The authors possess extensive knowledge and expertise regarding the crater, region and its inhabitants, acquired through several field visits conducted for other research endeavours.

3. Geographical and geological setting

The Lake Bosumtwi Impact Crater is a prominent geological feature situated in the Ashanti Region of Ghana, West Africa. It is located approximately on 6°30′N latitude

[1] https://en.geopark-ries.de/ (accessed 23 January 2026).
[2] https://www.vredefortdome.co.za/ (accessed 23 January 2026).
[3] https://www.ncaa.go.tz/ (accessed 23 January 2026).

and 1°25'W longitude, about 30 kilometres southeast of Kumasi the capital of the Ashanti region (Figure 1). The crater is almost entirely occupied by Lake Bosumtwi, a natural freshwater lake about 10 kilometres in diameter, making it the largest natural lake in Ghana. The surrounding terrain is characterized by a raised, terraced rim that rises between 100 and 200 meters above the lake surface, with the lake itself lying at an elevation of approximately 150 meters above sea level. Culturally, Lake Bosumtwi holds deep significance for the local Ashanti people, who consider it sacred, and the lakeside communities depend on it for artisanal fishing and modest tourism activities (Boamah and Koeberl, 2007).

Geologically (Figure 2) the Bosumtwi crater is a well-preserved complex impact structure formed approximately 1.07 million years ago during the early Pleistocene. The impactor is believed to have been a chondritic asteroid about 1 to 1.5 kilometres

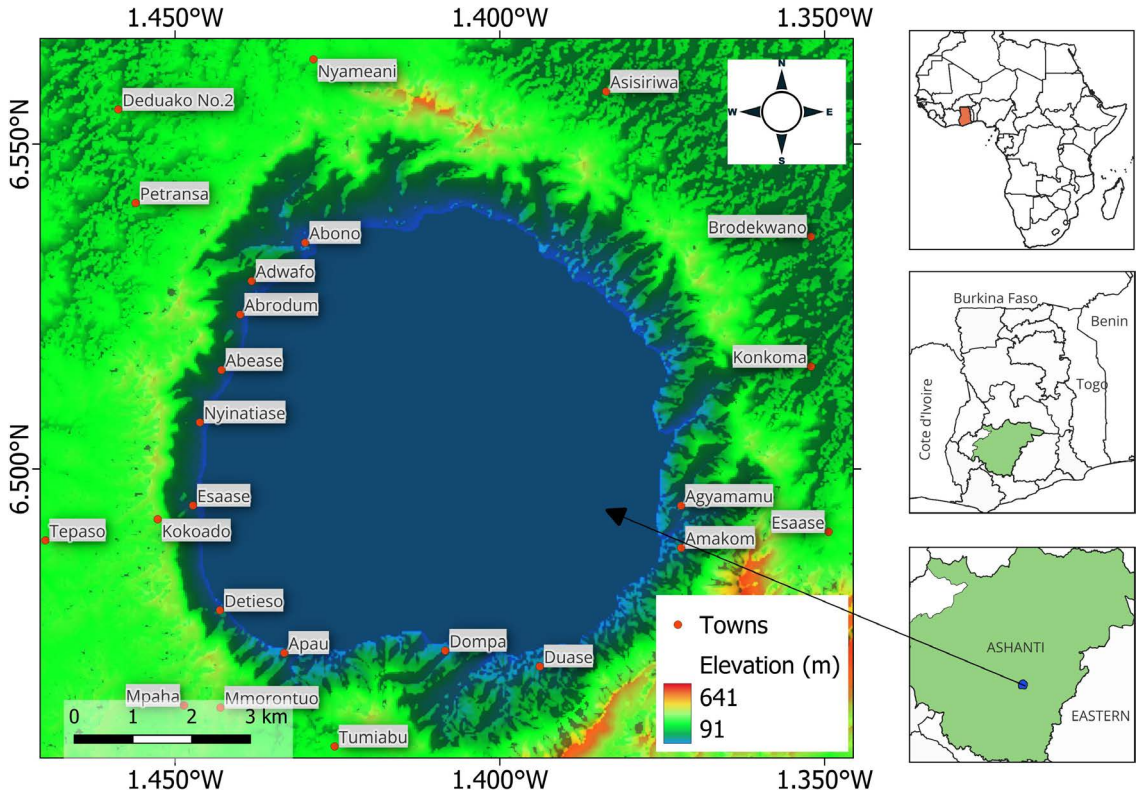

Figure 1. *Location of the Lake Bosumtwi Impact Crater (Lake Bosumtwi) in Ghana, West Africa.*

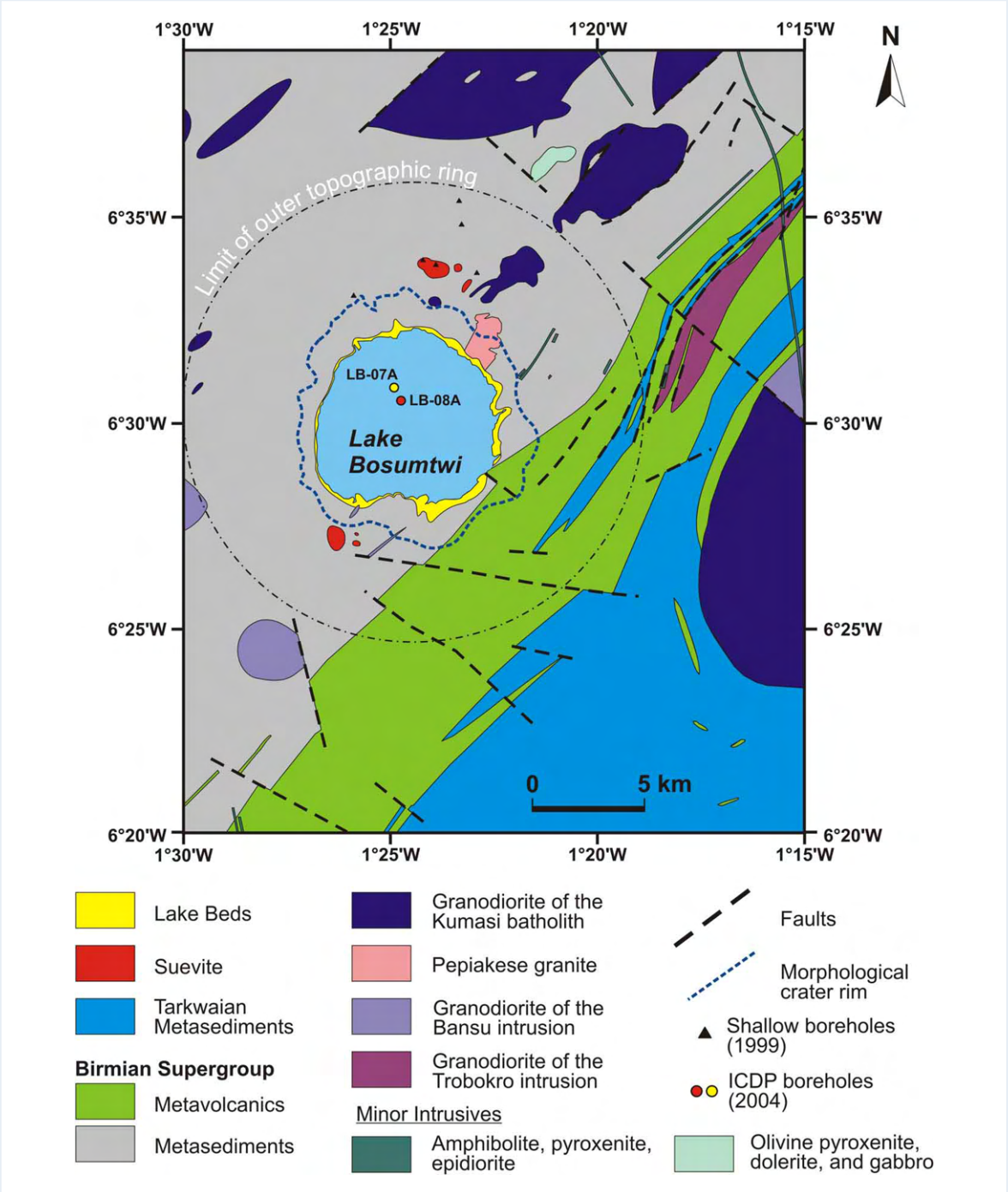

Figure 2. *Simplified geological map of the Lake Bosumtwi Impact Crater and surrounding areas (modified after Koeberl et al., 2007).*

in diameter, which struck the ancient crystalline rocks of the West African Craton. The target rocks primarily consist of Precambrian basement formations, including metasediments and metavolcanics of the Birimian Supergroup (around 2.1-2.2 billion years old), quartzites and phyllites of the Tarkwaian Group, and granitoids associated with the Proterozoic Eburnean orogeny. The structure exhibits classic complex crater morphology, including a terraced rim and a distinct central uplift, which is submerged beneath the lake and composed of breccia containing melt fragments and impact melt rock (e.g., Coney et al., 2010). Melt particle characteristics of the within-and out-of-crater suevites from the Bosumtwi impact structure have implications for crater formation. Diagnostic evidence of hypervelocity impact, such as shocked quartz and high-pressure polymorphs like coesite and stishovite, has been identified in drill cores and rim outcrops (e.g., Koeberl and Reimold, 2005; Ferrière, et al., 2007; Koeberl et al., 2007). The crater's preservation is exceptionally high due to its location within the tectonically stable West African Craton, which has experienced minimal deformation since the Proterozoic. Following the impact, the basin naturally filled with water, forming Lake Bosumtwi through a combination of high regional precipitation and surface runoff. As a closed basin with no natural outlet, the lake has accumulated finely laminated sediments (varves) that provide a continuous, high-resolution record of paleoenvironmental and climatic changes over the past one million years (e.g., Russell et al., 2003; Fox, 2006; Shanahan et al., 2012; Vinnepand et al., 2024). The synthesis of findings from these methodological approaches enabled the development of an evidence-based framework that addresses the specific gaps and opportunities identified at Bosumtwi while incorporating internationally recognized best practices in geoheritage management and community-centered conservation.

4. Significance of the Lake Bosumtwi Impact Crater

The Lake Bosumtwi Impact Crater possesses outstanding geological and geomorphological elements that granted it international scientific relevance and justified its designation among the International Union of Geological Sciences (IUGS) Second 100 Geological Heritage Sites (Koeberl et al., 2024). As one of the youngest, best-preserved, lake-filled (one of only six meteoric lakes globally) and most accessible complex impact structures on Earth, its nearly pristine morphology offers a unique natural laboratory. Key features of global relevance include its well-defined complex crater structure, characterized by a distinct, terraced rim rising 100-200 meters above the lake surface and a submerged central peak, a hallmark of high-energy impacts into crystalline bedrock. The crater's continuous lacustrine sediment archive provides a high-resolution, million-year paleoclimate record of the tropics,

capturing data on the West African monsoon and environmental shifts with annual precision in its varved layers. Moreover, the crater preserves a full suite of diagnostic impactites, including suevite breccias and shocked minerals like coesite, which are critical for validating hypervelocity impact models. Its formation within the stable West African Craton, devoid of significant tectonic overprinting, allows for the study of pristine post-impact modification. The crater has also been found to be associated with a swarm of tektites discovered in Ivory Coast (Koeberl, 1998) and is one of only four tektite strewn fields on Earth. These attributes collectively make Bosumtwi an essential terrestrial analog for interpreting impact cratering processes on other planetary bodies (e.g., Baratoux et al., 2019) cementing its status as a potential geoheritage site of the highest international rank.

The ecological significance of the Bosumtwi crater is anchored in its unique, closed-basin lake ecosystem, which led to its recognition as a UNESCO Biosphere Reserve (UNESCO, 2016a). The lake is a sanctuary of biological endemism and evolutionary adaptation, hosting several endemic fish species that have evolved in genetic isolation within this hydrologically confined system. This makes it a vital natural laboratory for studying speciation, adaptive radiation, and ecological resilience. The crater's steep, forested slopes and the lake's riparian zones support distinct microhabitats and transitional ecosystems, ranging from aquatic to upland forest communities, which enhance local biodiversity and serve as essential habitats. The Biosphere Reserve designation specifically acknowledges the area's role in integrating conservation with sustainable human use. It establishes a framework for protecting this fragile ecosystem from threats like deforestation, agricultural expansion, and overfishing, while promoting research, environmental education, and community-based stewardship. The reserve model emphasizes the balance between preserving the crater's unique biological heritage and supporting the livelihoods of lakeside communities, recognizing that the ecological integrity of Lake Bosumtwi is inseparable from the well-being of the people who depend on it.

The cultural heritage of the Bosumtwi crater is deeply interwoven with both tangible and intangible values rooted in the traditions of the Ashanti people. Tangibly, the crater and lake are central to local livelihoods, providing a source of recreation, water, fish, clay used for pottery and construction and tourism, resources that have sustained communities for generations. The lakeshore is dotted with historic villages, sacred groves, and ritual sites that materialize the long-standing human interaction with this landscape. Intangibly, Lake Bosumtwi is revered as a sacred and spiritual entity in Ashanti cosmology. It is believed to be the dwelling place of the god *Ɔtwee* and the souls of the deceased are thought to travel to its shores. This spiritual connection governs traditional practices, taboos, and communal rituals, including the annual *Akwantukese* (Great Migration) festival, which reinforces social cohesion and

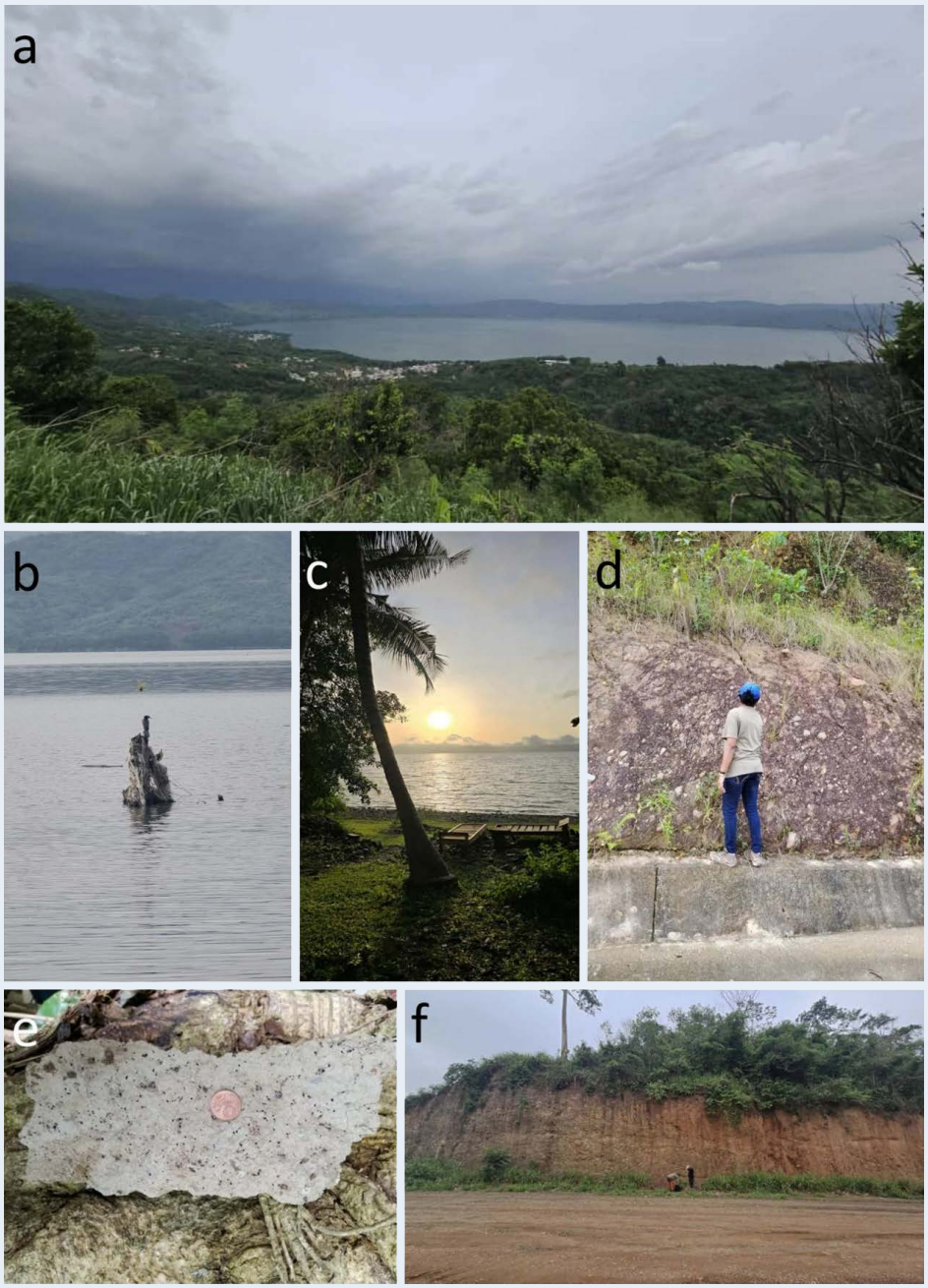

Figure 3. *Images from the Lake Bosumtwi Impact Crater showing (a) a panoramic view of the Bosumtwi crater lake, with settlements along the lake shore, (b) an image showing the lake with some wildlife activity, (c) an image showing leisure along the lake shore, (d) an image of an exposure of a deposit of impact breccia along a road cut on the outer rim of the impact crater, (e) an image of a suievite sample from the impact crater, (f) an image of an exposure of a deposit of impact breccia along a road cut on the inner rim of the impact crater.*

ancestral veneration. The crater itself is often interpreted through local etiological narratives that explain its origin through myth, frequently involving supernatural or divine intervention. These stories, passed down orally, encode indigenous environmental knowledge and ethical guidelines for resource use, forming a living cultural framework that has historically contributed to the conservation of the site. Together, these tangible and intangible values create a rich cultural landscape where geology, ecology, and human belief systems are inextricably linked, making Bosumtwi not only a scientific landmark but also a profound cultural legacy (Boamah and Koeberl, 2007; Visit Ghana, 2025).

5. Current threats and conservation challenges

The Lake Bosumtwi Impact Crater faces a range of interconnected threats that directly endanger its geological, biological, and cultural values and challenge the sustainability of its primary uses in research, tourism, and community livelihood (e.g., Amu-Mensah et al., 2017). These threats reveal critical conservation gaps that must be addressed through integrated and geoethically informed management.

5.1. Geological heritage and research

The scientific and geological value of the crater is undermined by both extractive research practices and a failure to translate knowledge into local educational capital. A primary threat to its geological integrity and geoheritage value stems from a history of extractive scientific research, which treats the site as a sample repository without fostering local scientific capacity or reciprocal benefit. For example, the International Continental Scientific Drilling Program (ICDP) project, while providing crucial paleoclimate data, exemplifies this model, as core samples were exported for international analysis with minimal local capacity development or retention of physical heritage (Koeberl et al., 2007; Boateng et al., 2023). This approach conflicts with contemporary geoethical principles of reciprocity, where scientific activities should provide tangible benefits and foster collaboration with local stakeholders (Stewart and Gill, 2017; Peppoloni and Di Capua, 2021; Koupatsiaris and Drinia, 2024). Furthermore, the site's immense educational potential as a natural laboratory for teaching impact cratering, stratigraphy, and earth history remains largely untapped due to a severe lack of interpretive infrastructure. The absence of a visitor center, educational displays, trained guides, or accessible digital resources means that high-level research does not translate into public

geoliteracy or local educational opportunities (e.g., Sapah et al., 2024a,b). This disconnect threatens the long-term preservation of geological heritage by failing to build a local constituency that understands and values the site's scientific significance.

5.2. Biological values and tourism

The unique closed-basin ecosystem of Lake Bosumtwi, which hosts endemic species and sensitive aquatic habitats, is increasingly degraded by unmanaged and unsustainable tourism. The primary biological threat is habitat degradation and pollution driven by unregulated visitor activity. With an estimated 70,000 visitors in 2024 (Ghana Tourism Authority, 2025), the site experiences pressure from inadequate waste management, unregulated construction along the shoreline, and nutrient influx, all of which compromise water quality and threaten endemic fish populations (Amuquandoh, 2010; Commey et al., 2019). The tourism model itself presents a second major threat as it is largely informal and economically extractive. Most visitor spending bypasses local communities, offering minimal job creation or incentives for conservation (Prakash et al., 2005; Bonsu et al., 2021). This lack of a structured, community-beneficial geotourism framework means that tourism growth directly threatens biological integrity without generating the revenue needed for environmental protection or the creation of local stakeholders invested in sustainable practices.

5.3. Cultural values and community-use

The crater's profound intangible cultural significance, particularly its sacred status in Ashanti culture, is directly threatened by both external activities and internal socio-economic pressures. Cultural conflict and disrespect arise when research and tourism activities proceed without proper consultation with traditional authorities, leading to the violation of traditional and spiritual protocols and eroding community trust (Boamah and Koeberl, 2007). Scientific investigations, including sampling, can be perceived as disrespectful intrusions into a spiritual landscape, creating tension between the values of research and the preservation of intangible heritage. Concurrently, socio-economic pressures and the erosion of traditional knowledge and practices threaten cultural continuity. Traditional fishing practices and indigenous ecological knowledge are being undervalued and weakening due to declining fish stocks, environmental change, and the marginalization

of local voices in governance. The lack of a formal framework to integrate Traditional Ecological Knowledge (TEK) into conservation planning (e.g., Cullen-Unsworth et al., 2012; Champagne-Côté et al., 2023; Todd et al., 2023) further alienates communities and severs the vital link between cultural practice and environmental stewardship.

5.4. Cross-cutting governance and policy

Underpinning all specific threats is a fundamental governance deficit and policy vacuum that prevents coordinated, effective conservation. Jurisdiction over the site is fragmented among multiple agencies, including traditional authorities, the Ghana Tourism Authority, the Forestry Commission, and district assemblies, with no overarching coordinated management framework. This leads to conflicting priorities, ineffective enforcement, and ad-hoc decision-making. Furthermore, Ghana lacks specific geotourism and geoheritage legislation, resulting in an inadequate regulatory environment for balancing protection with sustainable use. This governance gap is the critical barrier to implementing integrated solutions, such as a potential UNESCO Global Geopark (UNESCO, 2016b), which would require clear mandates, multi-stakeholder collaboration, and policies that explicitly recognize and protect the site's intertwined geological, biological, and cultural values.

5.5. Environmental degradation and illegal mining

The Lake Bosumtwi Impact Crater, faces severe threats from illegal mining activities, known locally as "Galamsey." Due to the location of the crater on a major gold belt in Ghana, it has continuously faced threats from gold seekers. This threat has significantly increased in recent years. These activities have led to extensive environmental degradation, posing a substantial conservation challenge. Galamsey operations have led to significant deforestation and habitat destruction, impacting biodiversity and the ecological balance of the region. The removal of vegetation for mining activities disrupts local ecosystems and contributes to land degradation. The use of toxic chemicals such as mercury and cyanide in Galamsey operations could result in severe soil and water contamination (Kuffour et al., 2018; Owusu-Boateng et al., 2022; Sapah, 2025).

An interpretive center at the Lake Bosumtwi Impact Crater, Ghana

6. Case study analysis

6.1. Geopark Ries, Germany

Geopark Ries in Germany is a UNESCO Global Geopark centered on the well-preserved Nördlinger Ries impact crater (Pohl et al., 1977; Sturm et al., 2013). It demonstrates the successful integration of geological heritage with societal needs through rigorous science communication, public education, and sustainable local development (Kaminski et al., 2017). The geopark's visitor centers and geotrails effectively translate complex impact science into accessible public narratives, fostering geoethical responsibility by emphasizing the site's planetary significance (Peppoloni and Di Capua, 2021). For Bosumtwi, Ries offers a blueprint for transforming scientific prominence into public engagement. The key lesson is the necessity of a scientifically accurate, community-integrated interpretive center that serves not only as an educational hub but also as the core of a local economic identity built around geoheritage. Unlike Ries, Bosumtwi lacks interpretive infrastructure, and collaborative governance needed to realize its potential.

6.2. Vredefort Dome, South Africa

The Vredefort Dome, the world's oldest and largest verified impact structure, is a UNESCO World Heritage Site. Its management model features a multi-level governance framework that coordinates local communities, provincial authorities, and national bodies, supported by diversified funding from fees, grants, and partnerships (Greffrath and Roux, 2012). Multiple visitor centers with interactive exhibits anchor its geotourism strategy, promoting education, local employment, and stewardship. However, Vredefort also faces ongoing challenges instructive for Bosumtwi: balancing conservation with peripheral development pressures, managing multi-jurisdictional complexity, and ensuring equitable distribution of tourism benefits across communities (Fleminger, 2022). For Bosumtwi, Vredefort illustrates the transformative potential of a high-level designation (e.g., UNESCO Global Geopark) while highlighting the critical need to anticipate and embed solutions for governance and equitable benefit-sharing from the outset

6.3. Ngorongoro Conservation Area, Tanzania

The Ngorongoro Conservation Area (NCA), a UNESCO World Heritage Site and part of the Ngorongoro-Lengai UNESCO Global Geopark, is a renowned example

of community-centred conservation. Governed by the Ngorongoro Conservation Area Authority (NCAA), it legally integrates the rights of indigenous Maasai communities, allowing residence and regulated grazing. A cornerstone of its success is the transparent revenue-sharing model, which directs a significant portion of tourism income to community projects, directly linking conservation to local prosperity (Galvin et al., 2015; Kegamba et al., 2022, Kegamba, 2024). The Olduvai Gorge Museum and Interpretive Center effectively communicate the area's geological, paleoanthropological, and cultural narratives. For Bosumtwi, NCA highlights the necessity of a formalized management authority and benefit-sharing mechanism that respects the cultural rights of the Ashanti people. The absence of a dedicated interpretive center at Bosumtwi represents a missed opportunity to similarly weave together geological significance, cultural heritage, and community well-being into a sustainable geotourism model. Pursuing a UNESCO Global Geopark designation could provide the essential framework for such integration.

7. The proposed framework: structure, stakeholders, and implementation

A comprehensive and actionable framework (Figure 4) for an interpretive center for the Lake Bosumtwi Impact Crater has been synthesized from the methodological approaches employed in this study. This framework is structured around three integrated pillars, supported by a detailed implementation strategy that identifies key stakeholders, funding mechanisms, and a phased operational plan.

7.1. The three core pillars of design and implementation

Pillar 1: Geoscience education through immersive and place-based learning

The center's educational design should move beyond static displays to interactive experiences that create a dynamic, multi-sensory learning environment. The proposed design includes the following steps:

- Immersive exhibits such as a state-of-the-art planetarium, where visitors are transported back in time to witness the cataclysmic asteroid impact that formed the Lake Bosumtwi Impact Crater, providing a dramatic cosmic context for the entire exhibit. 3D topographic crater model of the Lake Bosumtwi Impact Crater, crater formation simulations, where visitors can interact with a tactile topographic model and a hands-on crater formation simulator to understand the crater's science. A storytelling circle where Ashanti culture, myths, and folklore, especially

those related to the crater lake, are narrated and complemented by an interactive map where visitors can explore sacred sites through community-led videos. Finally, an aquarium with a digital guide of endemic species and ecosystem dioramas that simulate the crater environment, offering an immersive view of the entire living landscape.

- Curriculum-linked programs developed in partnership with the Ghana Education Service and the National Council for Curriculum and Assessment (NaCCA), which integrates the center into national STEM education and offers standardized field trips, hands-on workshops, and internship opportunities.
- A dedicated program to train and accredit local community members as "Geo-Guides" to act as knowledge interpreters, bridging the gap between academic science and public understanding. This creates employment and ensures an accurate knowledge of interpretation.

This approach aligns with modern geoscience education paradigms that emphasize outdoor and inquiry-based learning to foster a deeper connection with Earth sciences (Vasconcelos, 2016).

Pillar 2: Operationalizing geoethics through community-led governance

This pillar ensures the ethical management of the site by embedding geoethical principles into its core governance and operations. The proposed governance model includes the following:

- A community-led steering committee, comprising a majority of local and traditional representatives, would have decision-making power over center operations and tourism revenue allocation, ensuring community ownership.
- A code of conduct for visitors, developed in collaboration with traditional and community leaders, will regulate visitor activities in culturally sensitive and ecologically fragile areas and educate tourists on cultural protocols.
- Participatory resource monitoring that engages community members in citizen science initiatives such as monitoring the lake's water quality, crater rim integrity, tracking biodiversity, and fostering a sense of shared stewardship.

This pillar directly embodies the geoethical principles of responsibility, fostering public awareness, and co-developing knowledge with communities (Peppoloni and Di Capua, 2021).

Pillar 3: Social geosciences through community empowerment

This pillar focuses on delivering tangible socio-economic benefits, aligning geological heritage with community well-being, which is a core tenet of social geoscience (Stewart and Gill, 2017). The Bosumtwi interpretive center should be designed

as a sustainable geotourism enterprise. It should act as an anchor, spurring the growth of community-owned businesses, including guided tours, homestays, and local crafts. It should facilitate a participatory research and capacity building agenda where local knowledge informs scientific questions and international researchers are encouraged to collaborate with and build the capacity of local counterparts, thereby reversing extractive research practices. Additionally, a formalized revenue-sharing model through a transparent mechanism should direct a defined percentage of the center's earnings into a community development fund for local projects.

7.2. Center components and activities

The interpretive center is considered a multi-functional hub designed for education, conservation, and community. Its core components are as follows:

- An exhibition hall divided into three main galleries: i) a geological gallery displaying an interactive 3D crater model, meteorite impact simulations, impact breccias, tektites, meteorites, impacted host rocks, and educational panels; ii) a cultural heritage section highlighting Ashanti culture and crater lake mythology, traditional artifacts, and a digital map of sacred sites; and iii) a biodiversity zone featuring an aquarium of endemic species, interactive wildlife guides, and dioramas of the crater's ecosystems.
- An auditorium and events space consisting of at least 50 seats for presentations, documentary screenings, hands-on activities and workshops.
- A community engagement space open to community artisans for direct sales, youth for after-school programs, cultural performances, traditional craft demonstrations, and a weekly farmer's market.
- A research wing providing laboratory space for geoscience research including but not limited to geochemistry, geophysics, hydrogeology, hydrology, planetary geology and ecology, a digital archive of Bosumtwi research, and accommodation for visiting scientists and students to ensure research benefits are retained locally.
- Trails and guided experiences featuring a network of interpreted trails, including a crater rim trail, a cultural heritage walk through villages, outlooks for panoramic views of the crater, and night events for astronomy and sky gazing.

7.3. Stakeholder identification and roles

The success of the framework hinges on the active involvement of a clearly defined ecosystem of stakeholders comprising primary stakeholders, governmental agencies,

academic and research institutions and private partners. The primary stakeholders including the local communities of the crater-rim villages and the Ashanti people represented by the Ashanti Traditional Council serve as the site's cultural custodians, primary workforce, and co-creators of the visitor experience, ensuring authenticity and community ownership through their majority representation on the governing steering committee. Governmental Agencies such as the Regional Minister's office, District assemblies, Ghana Tourism Authority (GTA), Ghana Geological Survey Authority (GGSA), Ghana Institute of Geoscientists (GhIG), Environmental Protection Agency (EPA), and the Forestry Commission provide an essential enabling environment: the Office of the Regional Minister and District Assemblies facilitate political support and local integration, the Ghana Tourism Authority drives national marketing and visitor management, the Ghana Geological Survey Authority and Ghana Institute of Geoscientists guarantee scientific integrity and professional oversight, while the Environmental Protection Agency and Forestry Commission mandate and guide environmental conservation and sustainable resource management. Academic and research institutions including local and national universities (e.g., the Kwame Nkrumah University of Science and Technology and the University of Ghana) and other national institutions such as the Ghana Space Science and Technology Institute (GSSTI) form the intellectual backbone, responsible for co-designing educational curricula, leading participatory research from the center's facilities, and developing specialized content that links the crater to planetary science. Finally, private and development partners act as vital catalysts, where entities such as UNESCO, UNDP, IUGS, and the World Bank provide critical funding, technical assistance, and a pathway to global geoheritage status. Private sector Cooperate Social Responsibility (CSR) programs and diaspora communities offer investment, business expertise, and international ambassadorship to ensure financial sustainability and global reach. This type of collaborative network ensures that the center is a locally rooted, scientifically robust, and globally recognized initiative.

7.4. Funding strategy and sustainability plan

A diversified funding strategy and sustainability plan, fundamental to the viability of the center, is proposed. It combines capital investment with long-term operational sustainability. The requisite capital funding should be strategically sourced from a diversified portfolio including international development grants from bodies such as UNESCO and the World Bank, matched by dedicated grants from the Ghanaian government, and bolstered by private sector partnerships and corporate social responsibility initiatives. For long-term financial sustainability, operational

costs should be covered by a stream of internally generated revenues such as visitor entry fees, fees for specialized tours and educational workshops, and income from laboratory services within the research wing to researchers and academic institutions. This self-sustaining financial model should be further secured by establishing an endowment fund from donor contributions to create a financial buffer for future maintenance and unforeseen expenses.

Implementation of the project should follow a carefully sequenced, three-phase approach spanning at least 24 months, commencing with foundational community consultations and detailed design, advancing physical construction and comprehensive staff training, and culminating in a strategic launch. Beyond financial stability, the center's enduring legacy should also be anchored in environmental sustainability through a commitment to green architecture, solar energy, rainwater harvesting, a strict zero-waste policy, social sustainability, guaranteed employment of local staff, apprenticeship or intern programs, and the operation of a transparent revenue-sharing model that directly funds community projects, thereby fostering an unwavering sense of local ownership and ensuring that the community remains the primary guardian and beneficiary of the project.

7.5. Risk assessment and mitigation

A proactive risk management strategy is integrated into the framework implementation to address potential challenges. To mitigate the risk of funding delays, a phased development approach should be adopted, prioritizing critical foundational elements while actively diversifying funding sources beyond traditional grants. The risk of insufficient visitor numbers should be countered through strategic marketing partnerships with educational institutions and travel agencies, coupled with a focused appeal to specialized international tourism markets. To pre-empt cultural resistance and ensure deep local buy-in, the governance structure should, from its inception, integrate traditional leadership into core decision-making roles, complemented by the demonstration of tangible early benefits through pilot community initiatives. Finally, the risk of environmental degradation due to increased human activity will be managed through the strict enforcement of a co-developed visitor code of conduct, implementation of scientific carrying capacity assessments for all trails and facilities, and significant investment in resilient waste management infrastructure to preserve the site's ecological integrity.

7.6. Expected outcomes and impact

The framework is strategically designed to deliver significant, measurable benefits across multiple domains. The educational impact will manifest as a substantial increase in public geoliteracy, engaging a growing number of students and the public annually through structured, curriculum-linked programs and place-based education. Economically, the initiative is projected to catalyse a marked rise in visitor numbers, which will in turn generate a considerable number of direct employment opportunities within the center and a multiplier effect of indirect jobs across the local hospitality, transport, and artisan sectors. From a conservation perspective, the framework will actively strengthen the site's ecological and cultural integrity by embedding stewardship into the visitor experience, facilitating citizen science monitoring, and implementing dedicated environmental restoration programs. Ultimately, these concerted efforts will amplify the site's global scientific profile, positioning Ghana as a recognized hub for impact crater research and materially advancing the case for a future UNESCO Global Geopark designation.

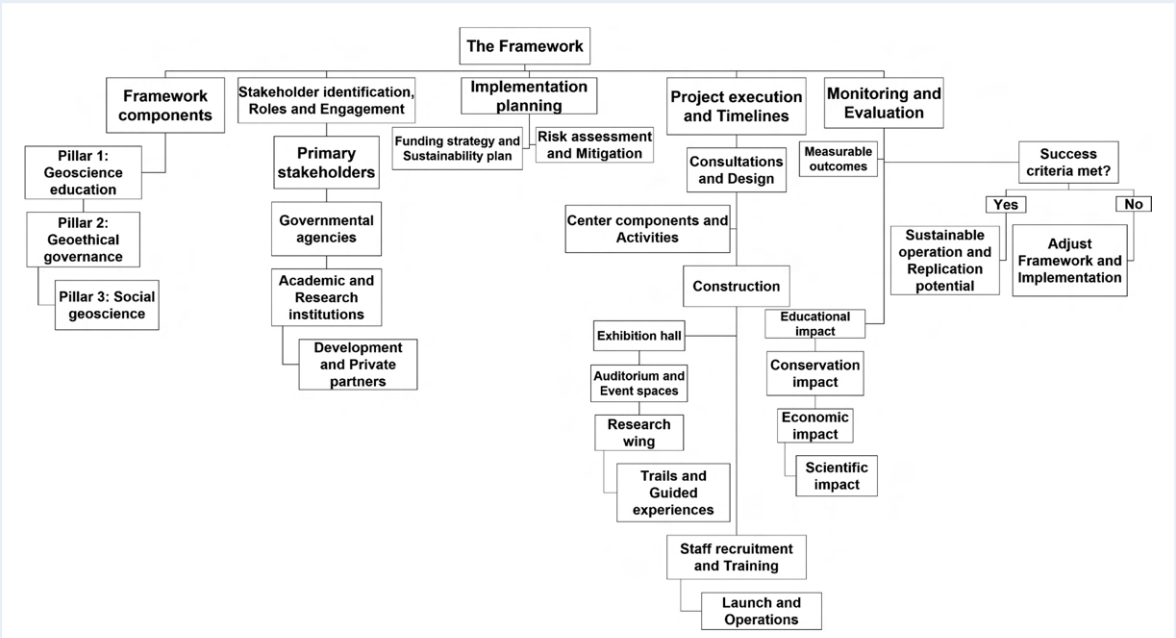

Figure 4. *A flow chart illustrating the framework for the design structure of an interpretive center for the Lake Bosumtwi Impact Crater.*

8. Discussion

8.1. Synthesizing lessons from case studies

The proposed framework for the Bosumtwi interpretive center is not conceived in isolation but is informed by a critical analysis of successful models. Each comparative case study provides a distinct yet complementary lesson in operationalizing the principles of geoethics, geoeducation, and social geoscience. The Ries Geopark in Germany is a global benchmark for translating complex geological science into an accessible narrative for the public. Its success is rooted in a world-class interpretive infrastructure that includes museums, visitor centers, and meticulously designed geotrails that transform the abstract concept of an impact event into an immersive experience. This model demonstrates the critical importance of professional science communication and shows how a geoheritage site can serve as a central pillar of regional identity and economic development, effectively creating a brand that benefits local producers and service providers. For Bosumtwi, the Ries exemplifies the necessity of investing in high-quality, engaging exhibits and trained interpretation to build a foundational understanding and appreciation among visitors. However, the European context of the Ries differs significantly from the Ghanaian reality, necessitating the inclusion of other models. The Vredefort Dome in South Africa provides a crucial lesson for adapting this scientific outreach to a developing world context. The most significant innovation lies in the professionalization of local community members as accredited field guides. This approach ensures the accurate dissemination of scientific knowledge, while creating direct employment and fostering a sense of local ownership and pride. Vredefort demonstrates that a bridge between international science and the local community can be built by empowering residents to become the primary storytellers and custodians of their heritage. However, Vredefort also grapples with the persistent challenges of managing a large, multi-jurisdictional site and ensuring equitable economic benefits. A cautionary tale underscores the need for robust, and inclusive governance from the outset.

This imperative for inclusive governance is expressed in the Ngorongoro Conservation Area in Tanzania. While it is primarily an ecological site, its governance model is very instructive. Ngorongoro's framework legally recognizes the rights of indigenous Maasai people to reside in and maintain their pastoral practices within the protected area, balancing conservation with human livelihoods. Its formal revenue-sharing mechanism, which directs a portion of tourism income to community projects, creates a tangible and direct link between conservation and local well-being. For Bosumtwi, where the Ashanti people's cultural and spiritual connection to the land is paramount, the Ngorongoro model provides the essential blueprint for ensuring

that the interpretive center is not an external imposition but a platform for cultural affirmation and equitable benefit sharing. This highlights that, without a governance structure that genuinely shares power and revenue with indigenous communities, long-term sustainability remains elusive.

In summary, the Bosumtwi framework represents a hybrid approach that strategically integrates the core strengths of these global exemplars. From the Ries Geopark, it adopts the commitment to scientific rigor and professional science communication. From the Vredefort Dome, it learns the strategy of community empowerment through training and employment as knowledge interpreters. And from the Ngorongoro Conservation Area, it embraces the foundational principles of community-centered governance and transparent benefit-sharing. By integrating these, the proposed framework for Bosumtwi moves beyond being a mere visitor facility to becoming a dynamic platform for geoethical practice. It actively works to decolonize geoscience by positioning the local community as co-creators and primary beneficiaries, thereby ensuring that the preservation of this planetary heritage is inextricably linked to the social and economic empowerment of the people who call it home.

8.2. The center as a platform for geoethical and decolonized practices

The proposed interpretive center represents a fundamental reimagining of the relationship between geological heritage, scientific practice, and local communities, serving as a practical manifestation of geoethical principles. By institutionalizing mechanisms for community co-creation, equitable benefit sharing, and participatory governance, the framework directly addresses the geoethical imperative of fostering social justice and reducing the geoscientific marginalization that has historically characterized sites of global significance (Peppoloni and Di Capua, 2021). This approach represents a decisive break from the extractive paradigm that has frequently defined international research at Bosumtwi, where scientific missions have often collected valuable data and samples while providing limited knowledge transfer, capacity building, or lasting benefits to local communities.

The center's governance model which grants the Community-led Steering Committee genuine decision-making authority over operations, programming, and financial management ensures that the residents and the Ashanti people transition from being subjects of research to becoming active agents in the curation and interpretation of their heritage. This structural shift is fundamental to decolonizing geoscience practices, as it challenges the conventional hierarchy of knowledge that typically privileges Western scientific perspectives over indigenous ways of knowing. By creating formal pathways for Ashanti's cosmological understandings, oral histories,

and traditional ecological knowledge not merely to complement but actively interact with geological science, the center validates Indigenous knowledge as equally crucial for developing a holistic understanding of place (Stewart and Gill, 2017). For instance, exhibits will not present the scientific narrative of meteorite impact and the Ashanti narrative of the lake's sacred origin as separate or competing explanations, but as interconnected strands of the site's profound significance.

Furthermore, the framework's embedded benefit-sharing mechanisms such as the direct allocation of a percentage of revenues to community development projects and the prioritization of local hiring and procurement, operationalizes the geoethical principle of reciprocity. This ensures that the conservation and promotion of the crater's global heritage translate into tangible improvements in local well-being, thereby aligning the site's protection with the community's own development aspirations. Therefore, the center becomes more than an educational facility. It becomes an engine for local economic resilience and a testament to the possibility of more equitable and ethically grounded geoscience. The model fosters a more socially robust and contextually relevant geoscience by positioning the community as co-creators, stewards, and primary narrators. One that is not only scientifically rigorous but also culturally respectful, socially just, and sustainable in the long term.

8.3. An integrated system for sustainable geoheritage

The proposed framework for the Bosumtwi Interpretive Center represents a transformative, integrated system that moves beyond conventional geoheritage management by fostering synergies among education, ethics, and economics. This holistic approach specifically addresses historical failures at Bosumtwi by adopting a hybrid governance model that combines the scientific outreach rigor of Vredefort Dome with the community-benefit ethos of Ngorongoro Conservation Area. The framework ensures that scientific knowledge is co-created through dialogue between researchers and local knowledge holders, creating a richer understanding that respects both evidence-based science and traditional wisdom while directly countering top-down, disconnected projects that previously undermined conservation efforts. Through the practical application of geoethical principles, the framework systematically decolonizes geoscience practice by reconfiguring power relationships and institutionalizing community leadership. The establishment of a community-led Steering Committee and formal revenue-sharing mechanisms transforms local communities from passive beneficiaries to active co-creators, managers, and primary narrators of their heritage. This institutionalization ensures that the preservation of planetary history becomes permanently linked to human empowerment, creating

a durable new paradigm for conservation that acknowledges and redresses historical inequities while building a sustainable future honouring both scientific truth and cultural identity.

9. Conclusion

This study has developed a comprehensive, evidence-based framework for an Interpretive Center at the Lake Bosumtwi Impact Crater, positioning it as a transformative model that integrates geoethics, geoscience education, and social geoscience into a cohesive system for sustainable geoheritage management. The proposed center is conceptualized not merely as a physical facility, but as a dynamic platform for redefining the relationship between a site of global scientific significance and the local community that is its cultural and spiritual custodian. This framework demonstrates how geological heritage can become a powerful catalyst for public geoliteracy, ethical scientific practice, and equitable local development, moving beyond extraction towards reciprocity.

The practical implications of this study are significant and actionable for multiple stakeholders. For geoethics practitioners, the framework provides a tangible, operational model for applying ethical principles in real-world geoscience contexts. It demonstrates how to institutionalize geoethical reciprocity through mechanisms like the Community-led Steering Committee, co-designed research agendas, and transparent revenue sharing. Practitioners can use this case to advocate for and implement similar governance structures that ensure scientific activities respect cultural values and deliver tangible local benefits, thereby shifting from extractive to collaborative research paradigms.

For educators and Geoscience communicators, the study highlights the critical need for place-based, immersive education that connects abstract planetary science to local landscapes and lived experiences. The proposed educational pillar, with its interactive exhibits, curriculum-linked programs, and accredited local Geo-Guides, offers a replicable blueprint for engaging diverse audiences, particularly in regions where geoscience is underrepresented in formal curricula. It underscores the role of interpretive centers as essential hubs for lifelong learning and for inspiring the next generation of scientists from within local communities.

For policymakers in Ghana, the study presents a clear, evidence-based argument for the development of national geoheritage and geotourism policy. The current gaps in legislation and fragmented management at Bosumtwi are identified as primary obstacles. Policymakers are urged to use this framework to draft specific regulations that recognize geoheritage sites, support community-based management, and create

pathways for designations like UNESCO Global Geoparks. Such policy development is essential to unlock sustainable tourism revenue, create green jobs, and conserve natural assets as part of national development strategy.

For local communities and traditional authorities, the framework validates the central role of communities as co-creators and primary beneficiaries. It provides a structured pathway for the Ashanti people to formalize their stewardship, safeguard intangible cultural heritage, and secure economic returns from tourism and research. This addresses a historical imbalance and offers a tool for communities to negotiate more equitable partnerships with external researchers and developers.

For the international research community, the study serves as a critical reflection on past practices and a guide for future ethical collaboration. It calls on researchers working at sites of high cultural sensitivity to adopt participatory methodologies, prioritize capacity building, and design projects that answer both global scientific questions and local community interests. The proposed research wing within the center is presented as a model for conducting science that leaves a positive, lasting infrastructure and knowledge base in the host country.

In terms of informing future practice and research, this study identifies several key avenues. Firstly, the framework itself requires piloting and adaptive management. Its implementation should be treated as an action-research project, with continuous monitoring of socio-economic, educational, and ecological outcomes. Secondly, it highlights the need for further comparative studies across Africa to refine community-benefit models in different cultural and governance contexts. Finally, it points to the necessity of interdisciplinary research that more deeply integrates geology, anthropology, education science, and political ecology to understand the complex dynamics of heritage conservation.

In conclusion, the successful realization of this initiative has the potential to establish a new benchmark for geoheritage management in Africa and the Global South. It presents a vision where the preservation of planetary history is inextricably linked to human dignity, cultural continuity, and economic resilience. By providing a practical roadmap that balances global scientific value with local rights and benefits, this framework offers a hopeful and replicable model for decolonizing geoscience practice and achieving truly sustainable development centred on our shared geological heritage.

References

Abreu A., Hernandez Salinas A., and Clüsener-Godt M., (2016). Sustainable management of the lake Bosomtwe in the Ashanti region of Ghana. UNESDOC Digital library,

SC-2016/WS/2, SC/EES/514GHA2000, 46 p., https://unesdoc.unesco.org/ark:/48223/pf0000243795 (accessed 23 January 2026).

Ajani H.A., and Ramaila S., (2025). Examining Extended Reality Instructional Tools for Virtual Field Trips in Nigerian High Schools. International Journal of Learning, Teaching and Educational Research, 24(9), 488-508. https://doi.org/10.26803/ijlter.24.9.24.

Amu-Mensah M.A., Amu-Mensah F.A., Akrong M.O., Darko H., and Addico G., (2017). Significance of Lake Bosomtwe as a freshwater resource in Ghana; communities' perception. International Journal of Development and Sustainability, 6(10), 1305-1318, https://isdsnet.com/ijds-v6n10-09.pdf (accessed 23 January 2026).

Amuquandoh F.E., (2010). Residents' perceptions of the environmental impacts of tourism in the Lake Bosomtwe Basin, Ghana. Journal of Sustainable Tourism, 18(2), 223-238. https://doi.org/10.1080/09669580903298531.

Ballantyne R., Packer J., and Falk J., (2011). Visitors' learning for environmental sustainability: Testing short- and long-term impacts of wildlife tourism experiences using structural equation modelling. Tourism Management, 32(6), 1243-1252. https://doi.org/10.1016/j.tourman.2010.11.003.

Baratoux D., Niang C.A.B., Reimold W.U., Sapah M.S., Jessell M.W., et al., (2019). Bosumtwi impact structure, Ghana: Evidence for fluidized emplacement of the ejecta. Meteoritics & Planetary Science, 54(10), 2541-2556. https://doi.org/10.1111/maps.13253.

Boamah D., and Koeberl C., (2007). The Lake Bosumtwi impact structure in Ghana: A brief environmental assessment and discussion of ecotourism potential. Meteoritics & Planetary Science, 42(4-5), 561-567. https://doi.org/10.1111/j.1945-5100.2007.tb01061.x.

Boateng C.D., Akurugu C.A., Wemegah D.D., and Danuor S.K., (2023). Underrepresentation of Local Researchers in Geophysical Studies at the Bosumtwi Impact Crater: Insights from A Systematic Review. Scientific African, 21. https://doi.org/10.1016/j.sciaf.2023.e01893.

Bonali F.L., Russo E., Vitello F., Antoniou V., Marchese F., et al., (2021). How Academics and the Public Experienced Immersive Virtual Reality for Geo-Education. Geosciences, 12(1), 9. https://doi.org/10.3390/geosciences12010009.

Bonsu P.O., Mensah R.O., Attah E.Y., Frimpong A., and Ewusi E., (2021). Infrastructure and Tourism Development at Lake Bosomtwe in the Ashanti Region of Ghana. Dutse International Journal of Social and Economic Research, 6(3), 89-100, https://fud.edu.ng/journals/DIJSER/DIJSER_Vol6_July2021/6_3/For%20print%20Vol%206%20No%203_splitPDF_Page89-100.pdf (accesses 23 January 2026).

Bouziat A., Schmitz J., Deschamps R., and Labat K., (2020). Digital transformation and geoscience education: New tools to learn, new skills to grow. European Geologist

Journal, 50, 15-19, https://eurogeologists.eu/bouziat-digital-transformation-and-geoscience-education-new-tools-to-learn-new-skills-to-grow/ (accessed 23 January 2026).

Brody M., (2015). Interpretive Centers. In Gunstone R., (ed.), Encyclopedia of Science Education, Springer, Dordrecht, pp. 542-544. https://doi.org/10.1007/978-94-007-2150-0_298.

Champagne-Côté R., Beaudoin J.M., Bélanger L., St-Onge M., Asselin H., et al., (2023). Indigenous leadership in creating a protected area: The Akumunan Biodiversity Reserve (Canada). Global Ecology and Conservation, 48. https://doi.org/10.1016/j.gecco.2023.e02681.

Commey V., Frimpong M., Akrofi-Ansah H., Osae-Akonnor P., Impraim E.C., et al., (2019). Destination Development for Entrepreneurial Tourism in Lake Bosomtwe and Kintampo falls (Ghana). In Bode J., and Freitag C., (Eds.), Universities, Entrepreneurship and Enterprise Development in Africa-Conference Proceedings 2018, Sankt Augustin, Germany, 13-14 September 2018, pp. 217-230. https://doi.org/10.18418/978-3-96043-071-1_217.

Coney L., Reimold W.U., Gibson R.L., Koeberl C., and Ogilvie P., (2010). Melt particle characteristics of the within-and out-of-crater suevites from the Bosumtwi impact structure, Ghana: Implications for crater formation. In Gibson R.L., and Reimold W.U., (Eds.), Large Meteorite Impacts and Planetary Evolution IV. Geological Society of America, Special Paper 465, pp. 411-442. https://doi.org/10.1130/2010.2465(21).

Cook M.L., Sheffield S.L., Ryan J.G., Bebeau C.M., and Rodgers M., (2025). Enhancing geoscience education through immersive virtual field trips: Student perspectives and implications for broadening participation. Journal of Geoscience Education, 73(4), 352-369. https://doi.org/10.1080/10899995.2025.2537995.

Cullen-Unsworth L.C., Hill R., Butler J.R., and Wallace M., (2012). A research process for integrating Indigenous and scientific knowledge in cultural landscapes: principles and determinants of success in the Wet Tropics World Heritage Area, Australia. The Geographical Journal, 178(4), 351-365. https://doi.org/10.1111/j.1475-4959.2011.00451.x.

Ferrière L., Koeberl C., and Reimold W.U., (2007). Drill core LB-08A, Bosumtwi impact structure, Ghana: Petrographic and shock metamorphic studies of material from the central uplift. Meteoritics & Planetary Science, 42(4-5), 611-633. https://doi.org/10.1111/j.1945-5100.2007.tb01064.x.

Fleminger D., (2022). UNESCO and the Vredefort dome. https://southafrica.co.za/unesco-vredefort-dome.html (accessed 23 January 2026).

Fox P.A., (2006). A 1 Ma West African Climate Change Record From Lake Bosumtwi, Ghana [Master's thesis, University of Akron]. OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=akron1145294568 (accessed 23 January 2026).

Galvin K.A., Boone R.B., McCabe J.T., Magennis A.L., and Beeton T.A., (2015). Transitions in the Ngorongoro Conservation Area: The Story of Land Use, Human Well-Being, and Conservation. In Sinclair A.R.E., Metzger K.L., Mduma S.A.R., and Fryxell J.M., (Eds.), Serengeti IV: Sustaining Biodiversity in a Coupled Human-Natural System, The University of Chicago Press, Chicago, USA, pp. 483-512, https://www.degruyterbrill.com/document/doi/10.7208/9780226196336-018/ (accessed 23 January 2026).

Ghana Tourism Authority, (2025). 2024 Tourism Report. https://ghana.travel/wp-content/uploads/2025/07/FINAL-2024-tourism-report-final.pdf (accessed 23 January 2026).

GhanaWeb, (2003). Lake Bosomtwe development committee formed. https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Lake-Bosomtwe-development-committee-formed-37321 (accessed 23 January 2026).

Greffrath G., and Roux C.J., (2012). The Vredefort Dome World Heritage Site: client satisfaction with commercial whitewater rafting: tourism and adventure. African Journal for Physical Health Education, Recreation and Dance, 18(1), 39-54. https://hdl.handle.net/10520/EJC119851.

Grieve R.A., (1990). Impact Cratering on the Earth. Scientific American, 262(4), 66-73. Retrieved from https://www.jstor.org/stable/24996714 (accessed 23 January 2026).

Horota R.K., Rossa P., Marques A., Gonzaga L., Senger K., et al., (2022). An Immersive Virtual Field Experience Structuring Method for Geoscience Education. IEEE Transactions on Learning Technologies, 16(1), 121-132. https://doi.org/10.1109/TLT.2022.3207089.

Kaminski M., Kaka S., and Kaminski M., (2017). The Nördlingen-Ries Geopark and nearby museums as a natural teaching laboratory for Geoscience students. Geophysical Research Abstracts, Vol. 19, EGU2017-12442, 2017, EGU General Assembly 2017, https://meetingorganizer.copernicus.org/EGU2017/EGU2017-12442.pdf (accessed 23 January 2026).

Kegamba J.J., (2024). Assessment of conservation institutional frameworks and benefit-sharing mechanisms for local peoples in the Greater Serengeti Ecosystem, Tanzania. Doctoral dissertation, Charles Darwin University. https://doi.org/10.25913/csgr-me69.

Kegamba J.J., Sangha K.K., Wurm P., and Garnett S.T., (2022). A review of conservation-related benefit-sharing mechanisms in Tanzania. Global Ecology and Conservation, 33. https://doi.org/10.1016/j.gecco.2021.e01955.

Koeberl C., and Reimold W.U., (2005). Bosumtwi Impact Crater, Ghana (West Africa): An Updated and Revised Geological Map, with Explanations. Jahrbuch der Geologischen Bundesanstalt, 145(1), 31-70. Retrieved from https://www.zobodat.at/pdf/JbGeolReichsanst_145_0031-0070.pdf (accessed 23 January 2026).

Koeberl C., Reimold W., Blum J., and Chamberlain C.P., (1998). Petrology and geochemistry of target rocks from the Bosumtwi impact structure, Ghana, and

comparison with Ivory Coast tektites. Geochimica et Cosmochimica Acta, 62(12), 2179-2196. https://doi.org/10.1016/S0016-7037(98)00137-9.

Koeberl C., Milkereit B., Overpeck J.T., Scholz C.A., Amoako P.Y., et al., (2007). An international and multidisciplinary drilling project into a young complex impact structure: The 2004 ICDP Bosumtwi Crater Drilling Project – An overview. Meteoritics & Planetary Science, 42(4-5), 483-511. https://doi.org/10.1111/j.1945-5100.2007.tb01057.x.

Koeberl C., Cavosie A., Baratoux D., Asiedu D. K., Sapah M.S., et al., (2024). Lake Bosumtwi Impact Crater. In Lozano G., Carcavilla L., Finney S., Hilario A., Vegas J., et al. (Eds.), The Second 100 IUGS Geological Heritage Sites, , IUGS – International Union of Geological Sciences, No. 199, pp. 266-267, https://iugs-geoheritage.org/geoheritage_sites/lake-bosumtwi-impact-crater/ (accessed 23 January 2026).

Koupatsiaris A.A., and Drinia H., (2024). Expanding Geoethics: Interrelations with Geoenvironmental Education and Sense of Place. Sustainability, 16(5). https://doi.org/10.3390/su16051819.

Kuffour R., Tiimub B.M., and Agyapong D., (2018). Impacts of Illegal Mining (Galamsey) on the Environment (Water and Soil) At Bontefufuo Area in the Amansie West District. Journal of Environment and Earth Science, 8(7), 98-107, https://www.iiste.org/Journals/index.php/JEES/article/view/43372 (accessed 23 January 2026).

Matias A., Carrasco A.R., Ramos A.A., and Borges R., (2019). Engaging children in geosciences through storytelling and creative dance. Geoscience Communication Discussions, 3(2), 167-177. https://doi.org/10.5194/gc-3-167-2020.

Melita A., and Mendlinger S., (2013). The Impact of Tourism Revenue on the Local Communities' Livelihood: A Case Study of Ngorongoro Conservation Area, Tanzania. Journal of Service Science and Management, 6(1), 117-126. https://doi.org/10.4236/jssm.2013.61012.

Mohammed A.K., (2014). Tourism development policy versus practice in Ghana: The case of Lake Bosomtwe Basin. European Scientific Journal, 10(7). https://eujournal.org/index.php/esj/article/view/2986 (accessed 23 January 2026).

Mohammed A.K., (2018). An Assessment of Tourism's Environmental Impact on the Lake Bosomtwe Basin. International Journal of Hospitality & Tourism Administration, 19(3), 259-288. https://doi.org/10.1080/15256480.2017.1324338.

Owusu-Boateng G., Sarpong K., Agyemang T.K., and Ampofo-Yeboah A., (2022). Assessment of Anthropogenic Activities, Environmental Literacy and Management Practices Impacting Lake Bosomtwe. International Journal of Environmental, Sustainability, and Social Science, 5(1), 239-251. https://doi.org/10.38142/ijesss.v5i1.140.

Peppoloni S., and Di Capua G., (2012). Geoethics and geological culture: awareness, responsibility and challenges. Annals of Geophysics, 55(3), 335-341. https://doi.org/10.4401/ag-6099.

Peppoloni S., and Di Capua G., (2021). Current Definition and Vision of Geoethics. In Bohle M., (Ed.) Geo-societal Narratives: Contextualising geosciences. Palgrave Macmillan, Cham, pp. 17-28. https://doi.org/10.1007/978-3-030-79028-8_2.

Peppoloni S., and Di Capua G., (2022). Geoethics: Manifesto for an Ethics of Responsibility Towards the Earth. Springer, Cham. https://doi.org/10.1007/978-3-030-98044-3.

Pohl J., Stoeffler D., Gall H.V., and Ernstson K., (1977). The Ries impact crater. In Roddy D.J., Pepin R.O., and Merrill R.B., (Eds.), Impact and explosion cratering: Planetary and terrestrial implications, Proceedings of the Symposium on Planetary Cratering Mechanics, Flagstaff, Arizona, September 13-17, 1976, New York, Pergamon Press, pp. 343-404.

Prakash S., Wieringa P., Ros B., Poels E., Boateng F.S., et al., (2005). Potential of ecotourism development in the Lake Bosumtwi Basin: A case study of Ankaase in the Amansie East District. SEFUT Working Paper No. 15, Albert-Ludwigs-Universität Freiburg. Retrieved from https://freidok.uni-freiburg.de/data/1748 (accessed 23 January 2026).

Russell J., Talbot M.R., and Haskell B.J., (2003). Mid-holocene climate change in Lake Bosumtwi, Ghana. Quaternary Research, 60(2), 133-141. https://doi.org/10.1016/S0033-5894(03)00065-6.

Sapah M.S., (2025). Ghana has a rare treasure, a crater made when a meteor hit Earth: why it needs to be protected. The Conversation, https://theconversation.com/ghana-has-a-rare-treasure-a-crater-made-when-a-meteor-hit-earth-why-it-needs-to-be-protected-260600 (accessed 23 January 2026).

Sapah M.S., Asiedu D.K., and Loh Y.S.A., (2024a). Geoscience education in Ghana: status and recommendations. Episodes, 47(1), 1-9. https://doi.org/10.18814/epiiugs/2023/023012.

Sapah M.S., Asiedu D.K., Loh Y.S.A., and Banoeng-Yakubo B.K., (2024b). Enhancing geoscience training in Ghana's tertiary institutions through geoconservation strategies. In Matshusa K., and Leonard L., (Ed.), GeoTourism for Social Sustainability and Ecological Justice in Sub-Saharan Africa: Unlocking the Potential, Routledge, London, pp. 122-146.

Schmieder M., and Kring D.A., (2020). Earth's Impact Events Through Geologic Time: A List of Recommended Ages for Terrestrial Impact Structures and Deposits. Astrobiology, 20(1), 91-141. https://doi.org/10.1089/ast.2019.2085.

Shanahan T.M., Beck J.W., Overpeck J.T., McKay N.P., Pigati J.S., et al., (2012). Late Quaternary sedimentological and climate changes at Lake Bosumtwi Ghana: New constraints from laminae analysis and radiocarbon age modeling. Palaeogeography, Palaeoclimatology, Palaeoecology, 361-362, 49-60. https://doi.org/10.1016/j.palaeo.2012.08.001.

Stewart E.J., Hayward B.M., Devlin P.J., and Kirby V.G., (1998). The "place" of interpretation: A new approach to the evaluation of interpretation. Tourism Management, 19(3), 257-266. https://doi.org/10.1016/S0261-5177(98)00015-6.

Stewart I.S., and Gill J.C., (2017). Social geology – integrating sustainability concepts into Earth sciences. Proceedings of the Geologists' Association, 128(2), 165-172. https://doi.org/10.1016/j.pgeola.2017.01.002.

Stöffler D., Artemieva N.A., Wünnemann K., Reimold W.U., Jacob J., et al., (2013). Ries crater and suevite revisited – Observations and modeling Part I: Observations. Meteoritics & Planetary Science, 48(4), 515-589. https://doi.org/10.1111/maps.12086.

Stronza A.L., and Gordillo J., (2008). Community views of ecotourism. Annals of Tourism Research, 35(2), 448-468. https://doi.org/10.1016/j.annals.2008.01.002.

Sturm S., Wulf G., Jung D., and Kenkmann T., (2013). The Ries impact, a double-layer rampart crater on Earth. Geology, 41(5), 531-534. https://doi.org/10.1130/G33934.1.

Teixeira I., Lima D., and Vasconcelos C., (2023). Storytelling as an Interdisciplinary Strategy in Geoscience Education. Education and New Developments, 528-532. https://doi.org/10.36315/2023v2end117.

Todd W.F., Towne C.E., and Clarke J.B., (2023). Importance of centering traditional knowledge and Indigenous culture in geoscience education. Journal of Geoscience Education, 71(3), 403-414. https://doi.org/10.1080/10899995.2023.2172976.

UNESCO, (2016a). UNESCO Man and Biosphere program: Lake Bosomtwe. https://www.unesco.org/en/mab/lake-bosomtwe (accessed 23 January 2026).

UNESCO, (2016b). UNESCO Global Geoparks: Celebrating Earth Heritage, Sustaining Local Communities. SC.2015/WS/32, UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000243650 (accessed 23 January 2026).

UNESCO, (2023). A sustainable management plan for Lake Bosumtwi in Ghana. https://www.unesco.org/en/articles/sustainable-management-plan-lake-bosumtwi-ghana (accessed 23 January 2026).

Vasconcelos C., (2016). Geoscience Education: Indoor and outdoor. Springer, Cham. https://doi.org/10.1007/978-3-319-43319-6.

Vinnepand M., Zeeden C., Wonik T., Gosling W., Noren A., et al., (2024). An age-depth model for Lake Bosumtwi (Ghana) to reconstruct one million years of West African climate and environmental change. Quaternary Science Reviews, 325. https://doi.org/10.1016/j.quascirev.2023.108478.

Visit Ghana, (2025). Lake Bosumtwi, https://visitghana.com/lake-bosomtwe/ (accessed 23 January 2026).

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