ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol 57, No.3 (2025): 472-479
DOI: 10.22146/ijg.107198 website: https://jurnal.ugm.ac.id/ijg

INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

New type of cave in the Tien Phuoc District, Quang Nam Province, Viet Nam

Giang N.T.T [(1), (2) (*)]; Nam Nguyen Xuan[(3)]; Hieu P.T[(1), (2)]; Minh Pham[(1), (2)]

[1]Faculty of Geology, University of Science, Ho Chi Minh City, Vietnam
[2]Vietnam National University, Ho Chi Minh City, Vietnam
[3)]Vietnam Center on Karst and Geo-Heritages; Vietnam Institute of Geosciences and Mineral Resources.

Received: 2025-05-28
Revised: 2025-08-27
Accepted: 2025-11-16
Published: 2025-11-17

Key words: Cave Vietnam; Bat Cave; Cave in metamorphic rock; faulting cave; geological heritage

Correspondent email :
ngttgiang@hcmus.edu.vn

Abstract Cave systems in Vietnam typically develop in limestone terrains, which cover about 20% of the national territory and are concentrated mainly in the north. In contrast, Tien Phuoc District (Quang Nam Province) is located in central Vietnam, featuring a hilly topography composed primarily of metamorphic rocks, with no previously recorded limestone terrain. The recent discovery of "Bat Cave," a notable scenic site in this region, has revealed a new type of cave development. Through geological, geomorphological surveys, and petrology analysis, the study identifies that Bat Cave formed within lime-bearing metamorphic rocks. Surface features, such as karren landforms—typically associated with karst terrain—indicate significant chemical weathering due to rainwater. The cave walls and floor also show signs of fluvial dissolution. Additionally, tectonic activity, including faulting and uplift, appears to have influenced the cave's formation, interacting with exogenous processes to shape the current landscape. These findings enhance the understanding of cave formation in non-limestone terrains and provide scientific support for recognizing geological heritage in Central Vietnam. This contributes to the foundation for establishing a future geopark in the region.

1. Introduction

Bat Cave is located in Tien An Ward, Tien Phuoc District, Quang Nam Province, Central Vietnam (Fig. 1), approximately 35 km southwest of Tam Ky City. Tien Phuoc is a midland district characterized by a relatively harsh climate, frequently affected by droughts and natural disasters. Although most of the land in this area is used for agriculture, it is generally of low fertility, contributing to the region's limited socio-economic development (Tran & Vu, 2009). The district's topography is dominated by denudation hills, with elevations ranging from 100 to 350 meters above sea level (asl), and is composed primarily of metamorphic and intrusive rocks (Nguyen et al., 1986; Tran & Le, 2018). Bat Cave is situated at an altitude of 120 m asl on the right bank of the Tien River. A notable geomorphological feature of this area is the unusual westward flow of the Tien River, which runs counter to the typical eastward drainage direction toward the sea. This phenomenon has earned the river the local designation of a "backward-flowing river" (Bui et al., 2022).

Recent field investigations and geomorphological analysis suggest that Bat Cave may represent a rare example of a cave system developed within metamorphic rocks, influenced by both exogenous and endogenous geological processes (Ford & Williams, 2007; Pham & Nguyen, 2015; La & Tran, 2009).

On the 1:200,000-scale geological map of the Hue–Quang Ngai sheet (Nguyen et al., 1986), Bat Cave is not explicitly assigned to any specific rock unit. The area is broadly designated as belonging to the Kham Duc Formation (PR_2*kđ1*), which has since been reclassified as the Kham Duc Complex (Tran & Vu, 2009). Notably, this complex includes a marble subunit with an estimated thickness of approximately 300 meters, which is likely the lithological unit in which Bat Cave developed. Additionally, Quaternary alluvial sediments are scattered along both banks of the Tien River in this area (Fig. 2).

Regionally, Bat Cave is situated within the Tam Ky–Phuoc Son Suture Zone, a geologically significant structure characterized by sub-parallel fault systems (Nguyen & Tran, 2010). This suture zone records complex tectonic activity, including the emplacement of ophiolitic bodies above the Precambrian basement and the formation of olistostrome sequences that were lithified during the Middle Paleozoic (Lepvrier et al., 2008; Tran et al., 2005). These endogenous geological processes have played a crucial role in shaping the current structural setting of the cave. Although Bat Cave has long been known to local residents, it has only recently attracted the attention of tourists. In response, the People's Committee of Tien An Ward (Tien Phuoc District) has initiated a policy to develop Bat Cave as part of a broader ecotourism strategy. This initiative aims to integrate the cave with nearby cultural and historical attractions, such as Loc Yen Ancient Village, the Memorial House of Huynh Thuc Khang and Lo Thung Stone Field, thereby forming a comprehensive tourist destination in the region (La & Tran, 2009; Tran et al., 2005).

2. Methodology

The study employed an integrated methodological approach comprising document synthesis and analysis; field

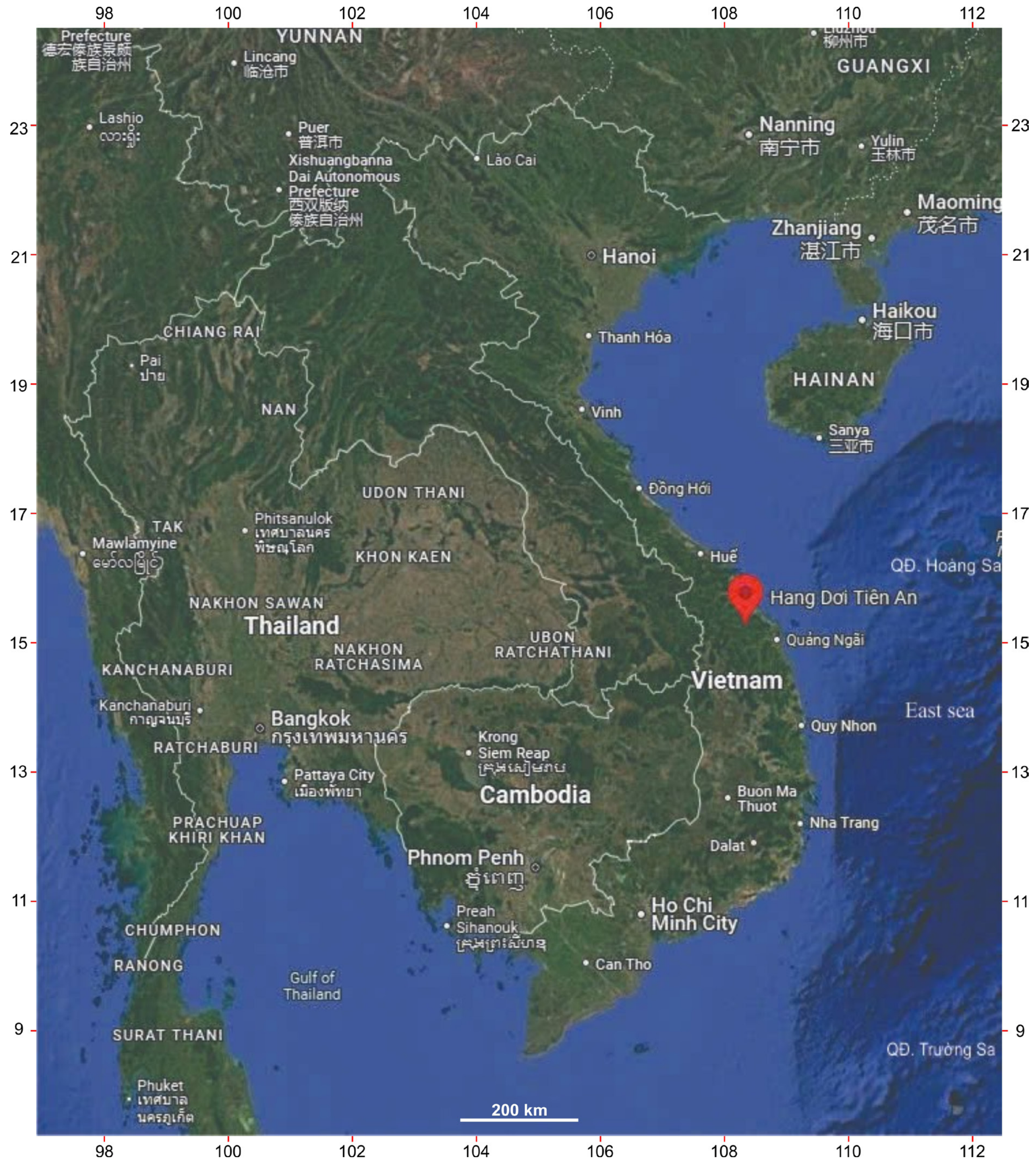

Figure 1. Location of Bat Cave, Tien An Ward, Tien Phuoc District, Quang Nam Province, Vietnam (Map background from Google Maps, edited by author, 2025).

investigation;traditional geological, geomorphological, and geographical techniques; as well asmapping, remote sensing, and Geographic Information System (GIS) applications.

As part of the third method, the study synthesized and built upon existing literature and research results related to regional geology and geomorphology, particularly those addressing structural geology, topographic features, and landform development. These documents were crucial for understanding the natural resources and geomorphological processes that shaped the cave environment.

Geological, geomorphological, and paleogeographical methods were employed to interpret the origin of local geological formations, assess their scientific significance as geoheritage, and analyze cave morphologies within the study area. A comprehensive field survey was conducted, with particular emphasis on the Tien Phuoc District of Quang Nam Province, to verify and expand upon existing data.

Through field investigations, the research identified key geological characteristics, topographic features, resource types, potential geotourism values, and the current status of tourism development. Additionally, representative sample points of different lithological units and terrain types were recorded. These data were subsequently used in remote sensing analysis to map the spatial distribution of geological formations, with a particular focus on locating and delineating the metacarbonate rock units in which Bat Cave has developed.

3. Result and Discussion

3.1. Geological characteristics

According to the 1:200,000-scale geological map compiled by Nguyen Van Trang et al. (1986), Bat Cave is located within the Kham Duc Formation (Proterozoic age, PR_2*kđ1*) (Fig. 2).

This formation comprises a diverse assemblage of metamorphic lithologies, including feldspar-hornblende schist (thickness ~500 m); two-mica-garnet schist, quartz-biotite schist, and biotite-disthene schist (~1,000 m); amphibole schist (~500 m); biotite schist, sillimanite-muscovite quartzite, and quartz-biotite-disthene-garnet schist (~1,000 m); quartz-muscovite schist (~300 m); and dolomitic marble (~300 m).

More recently, the unit has been reclassified as the Kham Duc Complex (Tran & Vu, 2009), and is characterized by a suite of metapelites, metapsammites, paragneisses, and amphibolites metamorphosed under greenschist to amphibolite facies conditions. Several authors have proposed that the metamorphic evolution of the Kham Duc Complex occurred in multiple stages. Osanai et al. (2004) and Usuki et al. (2009) suggest that the complex underwent high-pressure, medium-temperature metamorphism during the Early Paleozoic (~460 Ma), followed by thermal metamorphism under average pressure conditions at ~450 Ma. These metamorphic events were subsequently overprinted by tectonothermal activities associated with the Permian–Triassic orogeny. Although the rocks are broadly assigned to the Early Paleozoic, their precise age remains uncertain (Tran & Vu, 2009).

In the Bat Cave area, a lens-shaped body of metacarbonate rock with a thickness exceeding 60 meters has been delineated on the right bank of the Tien River, covering an area of approximately 0.8 km². These rocks appear as thin, strongly foliated strips, displaying medium- to large-sized lime cavities (ranging from 2 × 3 cm to 5 × 10 cm) that produce an eye-shaped structure (Fig. 3a, 3b, 3f). Distinct calcite veins are observed parallel to the foliation planes. Petrographic analysis under a polarizing microscope reveals that the metacarbonate rocks contain 80–90% calcite, with minor clay mineral content (~5–10%) (Fig. 3d, 3e).

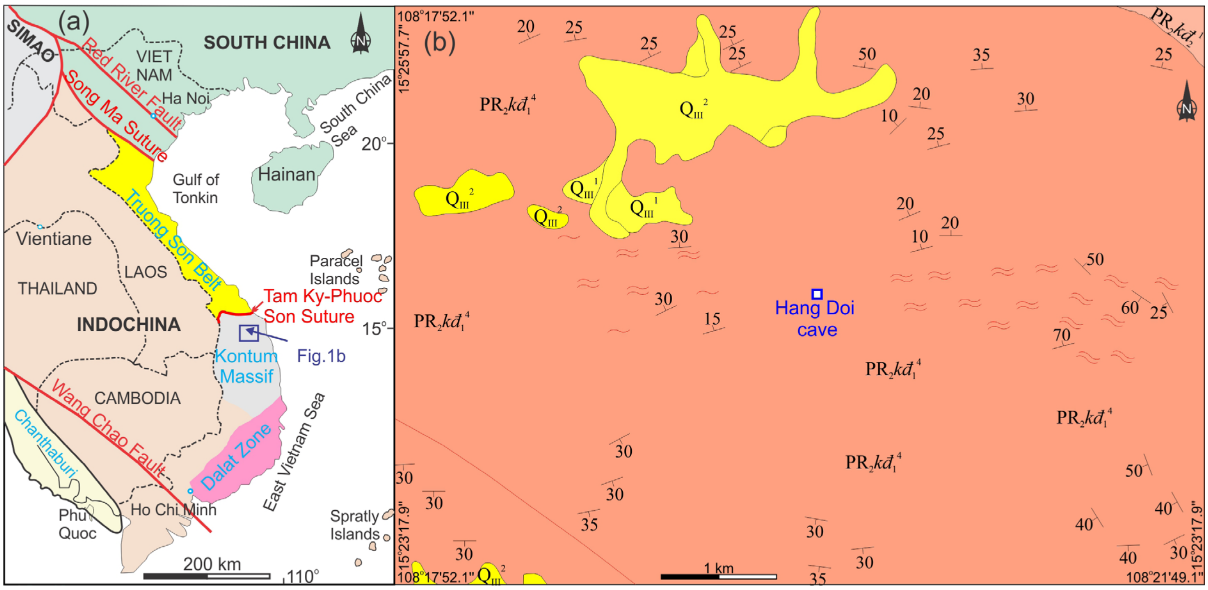

Figure 2. The geological map of the area surrounding the Bat cave.

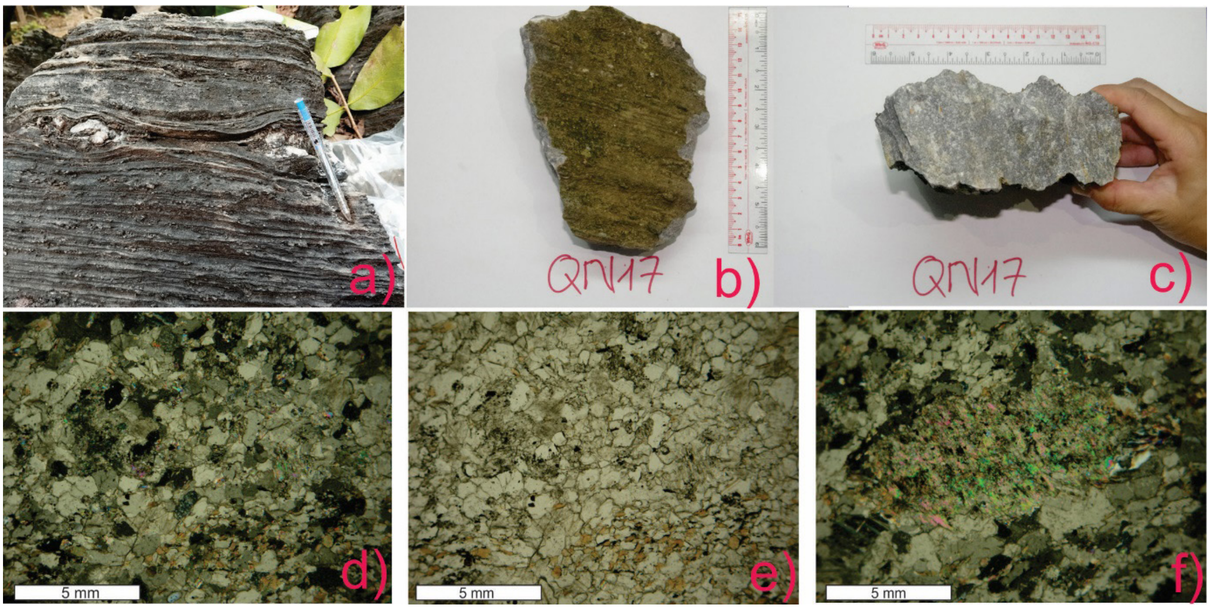

Figure 3. a) An eye-shaped structure; b) and c) Sample QN.17, metacarbonate, GPS: 15°25'32" 108°19'08"; d) Photo of a thin section under a polarizing microscope (2Ni+, 10X); e) Photo of a thin section under a polarizing microscope (1Ni-, 10X); f) Photo of an eye-shaped structure under a polarizing microscope (2Ni+, 10X)

Tectonically, the Bat Cave region is situated within the Tam Ky–Phuoc Son Suture Zone, a structurally significant feature in Central Vietnam that has attracted the attention of numerous researchers (Tran et al., 1979; Huynh & Nguyen, 1981; Trinh, 1995; Hai et al.; Bui et al., 2022). This suture zone is interpreted to represent a dual Benioff subduction system: one subducting beneath the Indosinian terrane during the Neoproterozoic, and the other beneath the Vietnam–Laos composite terrane during the Early to Middle Paleozoic. The tectonic collision processes associated with these subductions resulted in the emplacement of ophiolitic complexes that now overlie the Precambrian basement. These complexes include serpentinized ultramafic rocks such as pyroxenite, olivinite, and wehrlite. Radiometric dating using the K–Ar method yields an age of approximately 530 Million Years for these complexes. Field observations also reveal the presence of associated diabase-gabbro intrusions, plagioclase-amphibole schist, and greenstone units (mapped as PR_3*kđ1*), forming a sub-latitudinal arc that traverses the regions of Tam Ky, Phuoc Son, and Hiep Duc.

Along the suture zone, olistostrome formations and significant exogenous disturbances—likely triggered by rapid tectonic uplift and erosion—were subsequently cemented during the Middle Paleozoic. Metamorphic rocks within the suture zone exhibit a wide range of mineral assemblages and pressure-temperature conditions, including talc–kyanite, crocite-bearing schists, and epidote–amphibole assemblages. These metamorphic facies reflect the complex and polyphase metamorphic history of the region, indicating conditions ranging from low-temperature/medium-pressure to high-pressure environments (Hai et al.,2014).

3.2. Geomorphological characteristics

The area surrounding Bat Cave is characterized by a denuded hill terrain, with elevations reaching approximately 300 meters above sea level (Fig. 4). The hills expose a thick weathering crust composed predominantly of red-brown to yellow-brown soils. Vegetation is largely composed of planted forests, mainly used for pulpwood production. A valley lies between the hills at an elevation of around 100 meters, shaped by local erosional processes. The Bat Cave area is densely vegetated; its entrance is situated at the same elevation as the valley floor and features large exposed rock blocks and a small perennial stream (Fig. 5). The entrance is open and leads toward a steep rocky cliff, part of a broader mountain massif (Fig. 6). This cliff appears to have been shaped over time by fluvial erosion and the impact of driftwood, forming a distinct karst-like corridor approximately 800 meters in length, oriented NNE–WSW (Fig. 7). The cliff, approximately 30 meters high, displays visible marks of driftwood abrasion. Numerous large boulders scattered across the cave floor are likely the result of roof collapse (Fig. 8). The fact that most

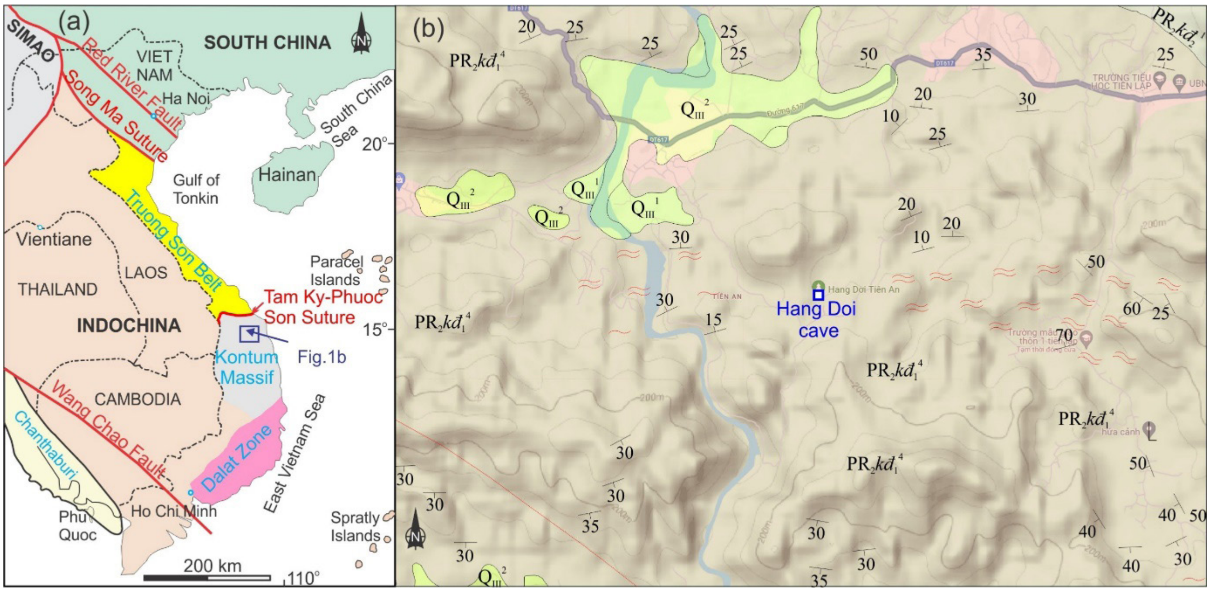

Figure 4. Geomorphological map of the bat cave area

Figure 5. Landscape outside the bat cave entrance.

Figure 6. The entrance and exit of Bat Cave, showing erosion marks on the cave walls caused by driftwood carried by water flows.

of these boulders remain angular, showing little evidence of rounding or prolonged exogenic weathering, suggests that the collapse events are geologically recent—possibly during the Quaternary period (Nguyen et al., 1986; Tran & Vu, 2009). In addition to the boulders, the cave bed also contains pebbles and gravel, indicating that it once functioned as an active stream bed. Deep niches and notches observed on both sides of the cliff further support the hypothesis of ancient fluvial activity, which likely contributed to the shaping of the Bat Cave's geomorphology (Brilha, 2016; La & Tran, 2009). These features are typical of caves influenced by both endogenic and exogenic geological processes (Brilha, 2016; Osanai et al., 2004; Usuki et al., 2009).

The term *karren*, derived from German, is widely used in karst research to describe a group of small-scale solutional landforms commonly found on exposed carbonate rock surfaces. These features are formed through surface corrosion—specifically, the chemical dissolution of carbonate rocks by slightly acidic rainwater or surface runoff (Ford & Williams, 2007). Karren features include grooves, runnels, pits, and furrows, reflecting the intensity and direction of water flow over time. In the Bat Cave area, karren-like features have been observed on metacarbonate outcrops, particularly along driftwood erosion grooves that developed on the rock surfaces (Fig. 9). These grooves are typically 3–5 cm deep and extend approximately 0.5–1 m in length, often arranged in linear patterns, indicating the directionality of erosional flow (Fig. 9b, c, d). Another striking form of driftwood-induced erosion is visible along the edge of a large rock block near the cave. Here, a trench-like groove, 0.5–1 m deep, cuts vertically across the schistose structure of the rock, suggesting high-energy flow events capable of transporting coarse woody debris (Fig. 9b). These erosional features support the interpretation that Bat Cave was formed not only through chemical dissolution typical of karst environments but also by mechanical erosion from surface water and debris transport. The presence of karren on metamorphosed carbonate rocks in this setting adds a unique dimension to the geomorphological significance of Bat Cave and supports its potential classification as a geosite of scientific interest (Brilha, 2016; Ford & Williams, 2007; La & Tran, 2009).

3.3. History of formation and development of the Bat cave

According to previous geological studies, the rocks of the Kham Duc Complex experienced three principal phases of metamorphism. The first phase involved regional metamorphism, which reached the greenschist facies. This metamorphic phase is believed to be associated with the formation of the Dai Loc granitogneiss dome. During this time, original magnesium-rich limestone layers were transformed into dolomitic limestone. The metamorphic conditions are estimated to have reached temperatures of 400–500 °C and pressures of 1–2 kbar (Cat et al., 1966).

The second phase involved contact metamorphism and metasomatism, driven by intensive magmatic intrusions. During this stage, the emplacement of large intrusive bodies led to strong recrystallization of the surrounding rocks. The metamorphic processes induced by high-temperature (P-T) contact led to the formation of calcium-silicate hornfels, indicative of exchange reactions between magmatic fluids and carbonate host rocks.

The third phase corresponds to Mesozoic dynamic metamorphism, during which the rocks of the Kham Duc Complex were intensely deformed and fractured along regional fault zones. Tectonic stresses during this period caused extensive mylonitization and displacement, contributing to the structural disruption of the rock mass.

Taken together, these metamorphic events suggest that the metacarbonate rock body in the Bat Cave area was likely segmented during the Mesozoic tectonic phase. The actual formation and development of Bat Cave, however, are hypothesized to have commenced much later, during the neotectonic period, under the combined influence of exogenous erosion and endogenous uplift (Tran & Vu, 2009; Osanai et al., 2004; Usuki et al., 2009). Although Bat Cave lacks the classic speleothems of karst systems, its location within a fractured metacarbonate formation aligns with hydrogeological patterns observed in Central Vietnam, where tectonic lineaments govern groundwater pathways and cave development (Nguyen & Pham, 2019).

4. Conclusion

A metacarbonate rock unit over 60 m thick and covering about 0.8 km² has been identified on the right bank of the Tien River. The rocks are strongly foliated, commonly boudinaged, and contain calcite veins parallel to foliation surfaces. Bat Cave lies at the intersection of at least three tectonic faults, showing clear evidence of tectonic influence. Further studies on its structural evolution and relation to the Tam Ky–Phuoc Son suture zone are needed to elevate its geoheritage value to national and international levels.

Geomorphologically, Bat Cave develops on a denudation–solution landscape at elevations below 100 m, surrounded by accumulation valleys with local base levels under 60 m. The cave shares surface features with karst terrain such as rugged, sharp karren forms but lacks stalactites. Morphologically, the cave extends about 200 m with vertical walls up to 25 m high. Fallen angular blocks and erosion traces on the walls indicate recent tectonic activity, while gravel and cobbles on the cave floor record past stream flows. Although Bat Cave does not meet the criteria of a karst cave, it holds long-standing cultural recognition and aesthetic appeal. Combining both natural and cultural aspects, it can be classified as a geomorphological–cave type of geoheritage, one of ten recognized geoheritage types in Vietnam.

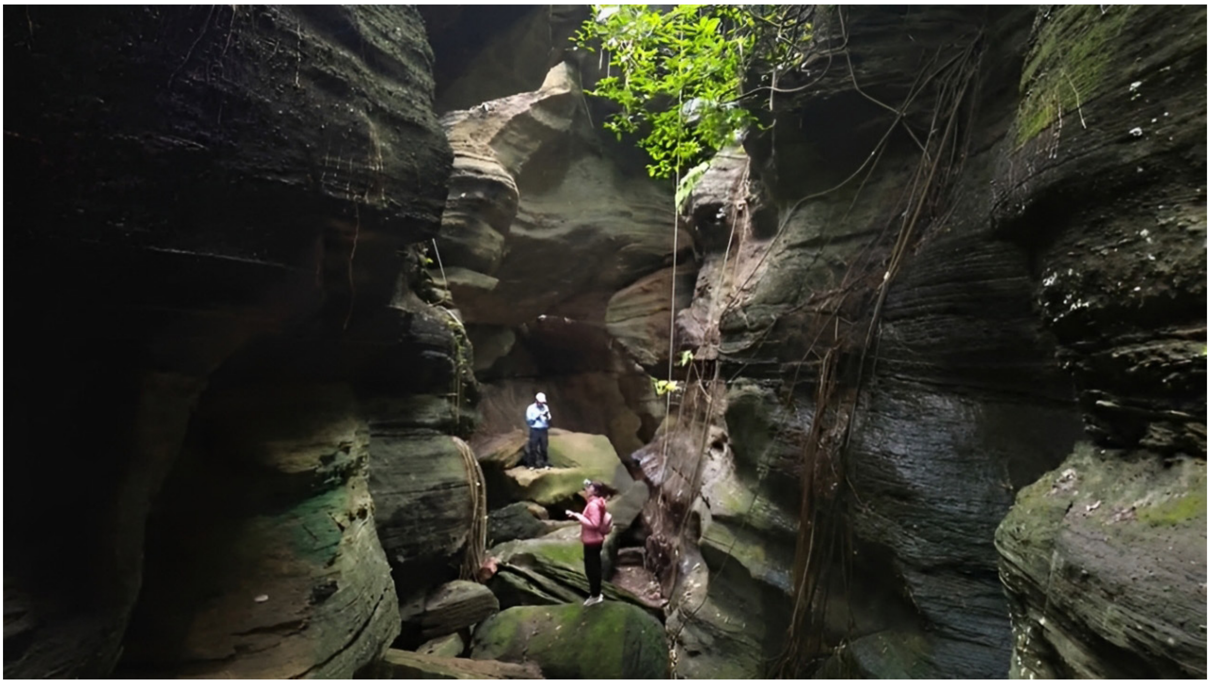

Figure 7. The majestic interior landscape of the cave.

Figure 8. a) The width of the passage is approximately 2–3 meters; b) There is evidence of at least two tectonic fault systems that have displaced the rock by approximately 30 centimeters.

Figure 9. Some types of karren in the Bat cave area: a) Observable areas of all karren types of a, b, c; b) Vertical groove-shaped karren in the wall; c) The karren develops along the crack; d) karren in line form on the surface.

Acknowledgement

This research is funded by University of Science, VNU-HCM under grant number T2024-52. Nguyen Thi Truong Giang was funded by the Master, PhD Scholarship Programme of Vingroup Innovation Foundation (VINIF), code VINIF.2024.TS.110.

Authors thank the anonymous reviewers for improving the manuscript.

References

Brilha, J. (2016). Inventory and quantitative assessment of geosites and geodiversity sites: A review. *Geoheritage*, 8 (2), 119–134. https://doi.org/10.1007/s12371-014-0139-3Brilha, J. (n.d.). Approaching an integrated qualification and evaluation system of the geological heritage. *Geoheritage*, 1–10.

Bui, T. T., Nguyen, T. D., Luong, Q. K., Bui, H. B., & Bui, V. S. (2022). Building a random forest predictive modeling of mineral perspectivity and mapping gold mineral prospects in Tam Ky - Phuoc Son, Quang Nam. *Journal of Mining and Earth Sciences,* 63(5), 82–92. https://doi.org/10.46326/JMES.2022.63(5).08

Cat, N. H., Nguyen, X. B., Pham, T. T., & Bui, V. M. (1966). *Geological Map of Ba Na–Hoi An,* scale 1:50,000. Geological Archives, Hanoi.

Ford, D.C., & Williams, P.W. (2007). *Karst hydrogeology and geomorphology* (rev. ed.). Wiley.

Google. (2025). Google Maps [Map]. Retrieved May 26, 2025, from https://www.google.com/mapsHai Thanh Tran, Khin Zaw, Jacqueline A. Halpin, Takayuki Manaka, Sébastien Meffre, Chun-Kit Lai, Youjin Lee, Hai Van Le, & Sang Dinh (2014). *The Tam Ky–Phuoc Son Shear Zone in central Vietnam: Tectonic and metallogenic implications. Gondwana Research*, 26(1), 144–164. https://doi.org/10.1016/j.gr.2013.04.008

Huynh, T., & Nguyen, X. B. (1981). Some characteristics of the Tam Ky–Phuoc Son suture zone. *Journal of Geology*, (Series A), Vietnam Institute of Geosciences and Mineral Resources. (*in Vietnamese*)

La, T. P., & Tran, T. V. (2009). Researching geological heritage and building a geopark in Vietnam. *Vietnam Department of Geology and Minerals,* 310, 10–19. (*In Vietnamese*)

Le, T. D., La, M. S., et al. (2014). Metamorphic characteristics and stratigraphic position of metacarbonate rocks in Thanh My area, Northern Quang Nam. *Geological Journal, Series A,* (346–348), 58–66. *(In Vietnamese)*

Lepvrier, C., Nguyen, V.V., Maluski, H., Phan, T.T., & Vu, V.T. (2008). Indosinian tectonics in Vietnam. *Comptes Rendus Geoscience,* 340(2–3), 94–111. https://doi.org/10.1016/j.crte.2007.10.005

Muhamad, M., Baiquni, M., & Wiryanto, W. (2024). *Sustainable tourism ecosystem in strategic national tourism area (KSPN) Borobudur Yogyakarta and Prambanan (BYP). Indonesian Journal of Geography,* 56(3), 515–524. https://doi.org/10.22146/ijg.96409

Nguyen, T. H., & Pham, V. B. (2019). Hydrogeological characteristics of karst systems in Central Vietnam. *Vietnam Journal of Hydrogeology,* 25(4), 60–70. *(In Vietnamese)*

Nguyen, V. D., & Tran, V. H. (2010). Structural characteristics of the Tam Ky - Phuoc Son shear zone and its relation to gold mineralization. *Vietnam Journal of Geology,* 35(2), 45–56. *(In Vietnamese)*

Nguyen, V. T., et al. (1986). Geological map series of Hue–Quang Ngai, 1:200,000 scale. Geological Archives, Hanoi. *(In Vietnamese)*

Osanai, Y., Nakano, N., Owada, M., Nam, T. N., Tsunogae, T., Toyoshima, T., & Binh, P. (2004). Permo-Triassic ultrahigh-temperature metamorphism in the Kontum massif, central Vietnam. *Journal of Mineralogical and Petrological Sciences***,** 99(4), 225–241. https://doi.org/10.2465/jmps.99.225

Pham, T. L., & Nguyen, V. H. (2015). Karst geomorphology and cave development in Central Vietnam. *Vietnam Journal of Earth Sciences,* 37(3), 210–220. *(In Vietnamese)*

Rohani, E. D., Baiquni, M., Wijono, D., & Suprihanto, J. (2023). Potential tourism attraction of Cokro Cave, Gunungkidul Regency as a special interest tourism development. *Indonesian Journal of Geography,* 55(2), 332–338. https://doi.org/10.22146/ijg.65987

Tran, V. T., et al. (1979). Geological map of Vietnam at a scale of 1:1,000,000 and accompanying explanatory notes. General Department of Geology. *(In Vietnamese)*

Tran, T. V., Vu, T. T., Đo, T., Nguyen, X. K., et al. (2005). Sustainable development of limestone areas in Vietnam. UNESCO Office, Hanoi. (*In Vietnamese*)

Tran, T. M., & Le, V. A. (2018). Metamorphic rock distribution and tectonic implications in Quang Nam province. *Journal of Geosciences*, 44(1), 33–42. (*In Vietnamese*)

Tran, V. T., & Vu, K. (2009). Vietnam's geology and resources. Natural Science and Technology Publishing House. *(In Vietnamese)*

Trinh, L. (1995). The tectonic significance of ophiolites in Central Vietnam. *Vietnamese Journal of Earth Sciences,* 4(1), 18–29. *(in Vietnamese)*

Usuki, T., Lan, C. Y., Tran, T. A., Wang, K. L., & Shellnutt, J. G. (2009). LA–ICP–MS U–Pb zircon geochronology and geochemistry of granitoids from the Kontum Massif: Evidence for multiple magmatic events in central Vietnam. *Journal of Asian Earth Sciences,* 34(1), 76–89.