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# Cave systems in Phong Nha - Ke Bang area

Nguyen Hieu[1,*], Vu Van Phai[1], Howard Limbert[2]

[1]*Faculty of Geography, VNU University of Science, 334 Nguyen Trai, Hanoi, Vietnam*
[2]*British Cave Research Association (BCRA)*

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**Abstract.** After 22 years with 13 collaborative research expeditions between the Faculty of Geography, VNU University of Science, and the BCRA, many caves in the great limestone blocks of Phong Nha Ke Bang have been explored and surveyed with a total length of 163km. Most of them are river caves, connected together to form three main systems: Phong Nha cave system, Hang Vom system and Nuoc Moc system. Phong Nha cave system starts from Hang Khe Ry - the world's longest river cave, to Hang Thung, En, Tra Anh and finally, Phong Nha cave, with a total length of 79.1km. Hang Vom system starts from Ruc Ca Roong cave and ends with Hang Vom with a total length of 44.3km. Nuoc Moc system which has a large basin located in the west of Chay River flowing through caves Vuc Ky, Nuoc Lan and Ha Lau is 14.1km long. Most recently, Son Doong Cave of the Phong Nha system was discovered and is the world's largest cave passage. Some caves have been developed for tourism activities such as Phong Nha Cave and Paradise Cave more recently. However, tourism activities have a large effect on the caves. Beside the research results of the cave systems in Phong Nha Ke Bang, this report will provide the following analyses: evaluation of the impact of tourist activities and environmental changes in the caves, and propose solutions for the effective management and sustainable development of this valuable resource.

*Keywords:* Caves, Phong Nha - Ke Bang, Son Doong.

## 1. Introduction

Phong Nha-Ke Bang, two huge limestone massifs in Quang Binh province, are the last large limestone blocks in the direction from north to south of Vietnam's territory. It has a long history of geological development, and is a convergence of many factors and favorable natural conditions such as lithology, tectonics, topography, hydrology... to form huge underground cave systems. In particularly, it holds world records such as the Khe Ry cave and Son Doong cave. After 22 years with 13 expeditions and cave research cooperation between the Faculty of Geography, VNU University of Sciences and the British Cave Research Association (BCRA), great underground cave systems in the limestone blocks of Phong Nha-Ke Bang have been discovered and surveyed with a total length of 163km. Most of caves here are the river caves, interconnecting to form three main systems: Phong Nha system, Hang Vom system, and

* Corresponding author. Tel: 84-4-38581420.
E-mail: nguyenhieu@hus.edu.vn

Nuoc Moc system. These precious natural resources of the World, Vietnam and Quang Binh, can be exploited by using multiple objectives for conservation as well as economic and social development, student development designs for local communities.

## 2. Limestone massif Phong Nha - Ke Bang and mysterious cave systems

### *2.1. Characteristics of limestone massif Phong Nha - Ke Bang and large cave potential*

*Geological characteristics*

The geological characteristics of the Phong Nha - Ke Bang, the diversity of structure and stratigraphy, is the sum of the product of six major stages of development in the history of the Earth's crust in the region: Late Ordovician period - Silurian, Devon - early Carbon, and Carbon - Permian stages; Mesozoic period: Cretaceous;

Cenozoic stage: Neogen and Quaternary. These are the conditions which created the diversity of the unique landscape of karst terrain and great underground systems of caves in the karst block Phong Nha - Ke Bang National Park.

Phong Nha-Ke Bang also presents geological events demonstrating the historical development of lively crust over 500 million years, from the Ordovician to the present. Complex tectonic activity of the Earth's crust is the cause of all of the formation and fracture of the geological structure, which is the evolutionary spiral to create a normal geological and geomorphological picture today. Geological structures and lithological composition diversity is crucial to the diversity of topography and geomorphology and also affects the decision network hydrology, ground water, climate - the physical geography, biodiversity and environmental landscape of a wild and mysterious land of nature [1].

Research studies are mainly in the Truong Son structure zone (AE Dovjikov and et al, 1965), which is separated from the Hoanh Son zone by faulting Song Ca - Rao Nay, including Dong Hoi lift blocks and blocks drop Phong Nha - Quy Dat. Dong Hoi lift blocks exposed in the south-east of the study area were created from the terrigenous rocks of Ordovician-Silurian age. At the center of Dong Hoi lift blocks, also granitoids blocks of the Truong Son basis create complex structures "dome anticlinal". Slump blocks Phong Nha - Quy Dat are exposed in the central part of the Truong Son zone and are composed of terrigenous rocks, alternating carbonate rock, including Cat Dang formation ($D_3$ *cđ*). The terrigenous sedimentary rocks containing organic litter, silica and silica carbonate of La Khe formation ($C_1$*lk*) and carbonate (Bac Son formation - CP *bs*) covers unaccordantly on the Cat Dang formation, also involved in mass loss above Cretaceous sediments (of Mu Gia formation - K *mg*), and Cenozoic sediments.

There are two main fault systems and two secondary fault systems. The two main systems are NW-SE and NE-SW trend and the two secondary systems are of longitudinal and latitudinal trend.

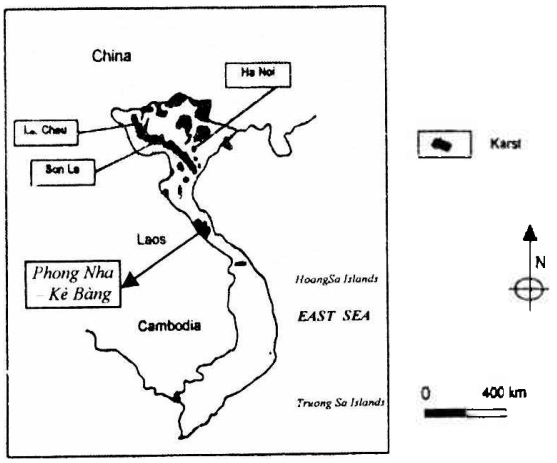



Figure 1. Karst areas of Vietnam.

*Geomorphological Characteristics*

The diversity of geological structure - petrographic combination with the humid tropical climate of Vietnam has created the diversity of the landforms within the Phong Nha - Ke Bang, including karst and non-karst landforms. Although the central massif in form is class size and less differentiated, but overall, the landscape of Phong Nha - Ke Bang is differentiated in the direction of decreasing altitude from south to north and from west to east. The southernmost part of the region is the mountain range with an average altitude of 1200 - 1600m and peaks comfortable wavy long sub - parallel in the west to the east-south-east.

This is a collection of tubs for the limestone massif in the north. From south to north, the limestone blocks have a relatively uniform height, about 700-900m.

From west to east, limestone blocks of the Ke Bang form the watershed area between the eastern and western Truong Son. The Vietnam-Laos border areas include top limestone flooring floors each with a height of 800-1000m. There exist some peaks of 1200 - 1600m made of red sandstone rock of Mu Gia formation, in the Mu Gia Pass area. From west to east, the lower limestone terrain is 600 - 700m and the eastern edge is moved down in steps to 400-500m and 200-300m. The 100m relief level is formed by the non-karst rocks common in the eastern part of the region.

The non-karst topography distribution around limestone blocks of Phong Nha - Ke Bang, is formed by geomorphological processes on the terrigenous sedimentary rocks and intrusive rocks, and this is also the basin for water supply to karst processes and materials (mud, sand, gravel, cobbles, gravel, etc.) which are deposited in the caves as well as the area of Phong Nha - Ke Bang. The main water sources are abundant from this vast region, and have created more favourable conditions for the development of the biological world in particular and caves in the karst area in general.

Karst landforms are the most characteristic feature of the limestone blocks Phong Nha - Ke Bang. First, they account for more than 2/3 of the heritage region, and this is the largest limestone massif still relatively intact in Vietnam and continuing through Hin Namno of Laos, it becomes the largest limestone massif on the planet. This limestone block of 1000m thickness, is mainly old limestone Carbon - Permian high-purity, texture blocks or subclass thick. In these conditions karst evolution occurs radically: From the period of many small karst funnel cone karst, as it is the final form of the tower and karst plain. The limestone formations in Phong Nha - Ke Bang also have many characteristics of the limestones in Ha Long Bay, Northern Son (Lang Son province), Ha Giang, Son La and Southern China. But the location of the limestone in the tectonic regime, climate and relationships with the surrounding non-karst terrain are not the same. At Ha Long Bay, the limestone blocks are in shallow bays along the continental margin, rising above the sea as hundreds of small islands. Bac Son, Ha Giang, Son La and China in general, limestone blocks are distributed in the mountains far from the sea and higher than the surrounding non-karst terrain. Particularly in Phong Nha - Ke Bang the limestone terrain is lower than the surroundings.

For these reasons the evolution of karst landforms in Phong Nha-Ke Bang is not exactly the same as elsewhere, although this evolution occurs by the same mechanisms; dissolution (both surface water and groundwater) and

mechanical damage (due to landslides on the slopes and in caves). Due to these mechanisms, many styles and types of karst topography have been created both on the surface and deep below.

### *2.2. Characteristics of cave systems in Phong Nha-Ke Bang*

#### *a) Cave systems and their scale*

Some cave systems with many caves in the great limestone blocks of Phong Nha Ke Bang have been explored and surveyed with a total length of 163km. Most of them are river caves, connected together to form three main systems. Phong Nha cave system, Hang Vom system and Nuoc Moc system. Phong Nha cave system starts from Hang Khe Ry - the world's longest river cave *(table 1)*, to Hang Thung, En, Tra Anh and finally, Phong Nha cave, with a total length of 79.1km. Hang Vom system starts from Ruc Ca Roong cave and ends with Hang Vom with a total length of 44.3km *(fig 3)*. Nuoc Moc system which has a large basin located in the west of Chay River flowing through caves Vuc Ky, Nuoc Lan and Ha Lau is 14.1km long.

Nuoc Mooc system is a large resurgence on the west bank of the Chay River. We are trying to find caves leading into this system. High level stream sinks at 800m altitude south of the Xuong valley have been explored to over 300m deep. Many other caves west of the Chay River may lead into this system. The source of the Nuoc Mooc water is still unknown. There is potential for a very long system south and west of the Chay River.

Table 1. Longest caves of Vietnam [2, 3÷11]

| Cave Name | Province | Length | Year | Exploration |
|---|---|---|---|---|
| Hang Khe Rhy | Quang Binh | 18,920m | 1997/1999 | British |
| Hang Vom | Quang Binh | 15,760m | 1992/1994/09 | British |
| Hang Son Doong | Quang Binh | 8,573m | 2009/10 | British |
| Hang Co Ban | Son La | 8,500m | 1994/1998 | British/French/Italian |
| Hang Phong Nha | Quang Binh | 8.329m | 1990/92/2010 | British |
| Nguom Ban San | Lang Son | 5,416m | 2001/2003 | British |
| Nguom Sap | Cao Bang | 5,379m | 1997/1999 | British |
| Hang Toi | Quang Binh | 5,258m | 1990/1992 | British |
| Hang Cha Lo | Quang Binh | 4,483m | 2007 | British |
| Hang Duat | Quang Binh | 3,927m | 1994 | British |
| Hang Lanh | Quang Binh | 3,753m | 2001 | British |
| Ban Ngam | Cao Bang | 3,600m | 1995 | French/Italian |
| Vuc Ky | Quang Binh | 3,460m | 2012 | British |
| Hang Thung | Quang Binh | 3,351m | 1994 | British |
| Nguom Nam Lao | Cao Bang | 3,360m | 2001 | British |
| Ki Lu | Cao Bang | 3,353m | 2003 | British |
| Hang Ca-Be | Lang Son | 3,342m | 1992 | British |
| Nguom Pac Bo | Cao Bang | 3,248m | 1997 | British |
| Hang Over | Quang Binh | 3,244m | 1997 | British |
| Pac Lung | Cao Bang | 3,109m | 2001 | British |
| Bo Luong | Lang Son | 3,094m | 2003 | British |
| Hang Nuoc | Hoa Binh | 3,075m | 2003 | British |
| Bo Nhon | Lang Son | 3,057m | 2003 | British |
| Hang Ken | Quang Binh | 3.018m | 2010 | British |

The above characteristics show that for both cave systems the entrance is at the current water level of rivers and streams. The systems can be seen as the largest scale river caves discovered in Asia so far.

*b) Cave levels*

Five levels of cave development have been identified in the Ke Bang Massif. Namely; 0 m; 20 ± 5 m; 50 ± 10 m; 100 ± 10m and 200 ± 50 m [12]. A sixth level at 350-400m was suggested after the 2010 expedition.

Level 1 or 0m is taken as the modern stream cave level. This includes all the river caves such as Phong Nha, Khe Ry and Hang Vom; Level 2 at 20m includes the dry entrance to Nuoc Nut, passage in Hang Over and Hang Vu Ca Tau; Level 3 at 50m includes Hang Trau and Hang Tron;

Level 4 at 100m, can be seen in the dry high level cave above Phong Nha, Hang Tien Son, and in Hang Gio; Level 5 at 200m is seen in Hang Hai Cua and Hang Hoa Huong; The evidence for level 6 at 350-400m now includes more than 10 caves, between 500 and 1000m long, following the 2012 expedition. These are large mainly horizontal caves with extensive calcite deposits. In many cases the cave ends with a complete calcite blockage. Caves at this level include Hang Ho Nui, Hang 1987, Hang Cua Nho and Hang Ho Ky.

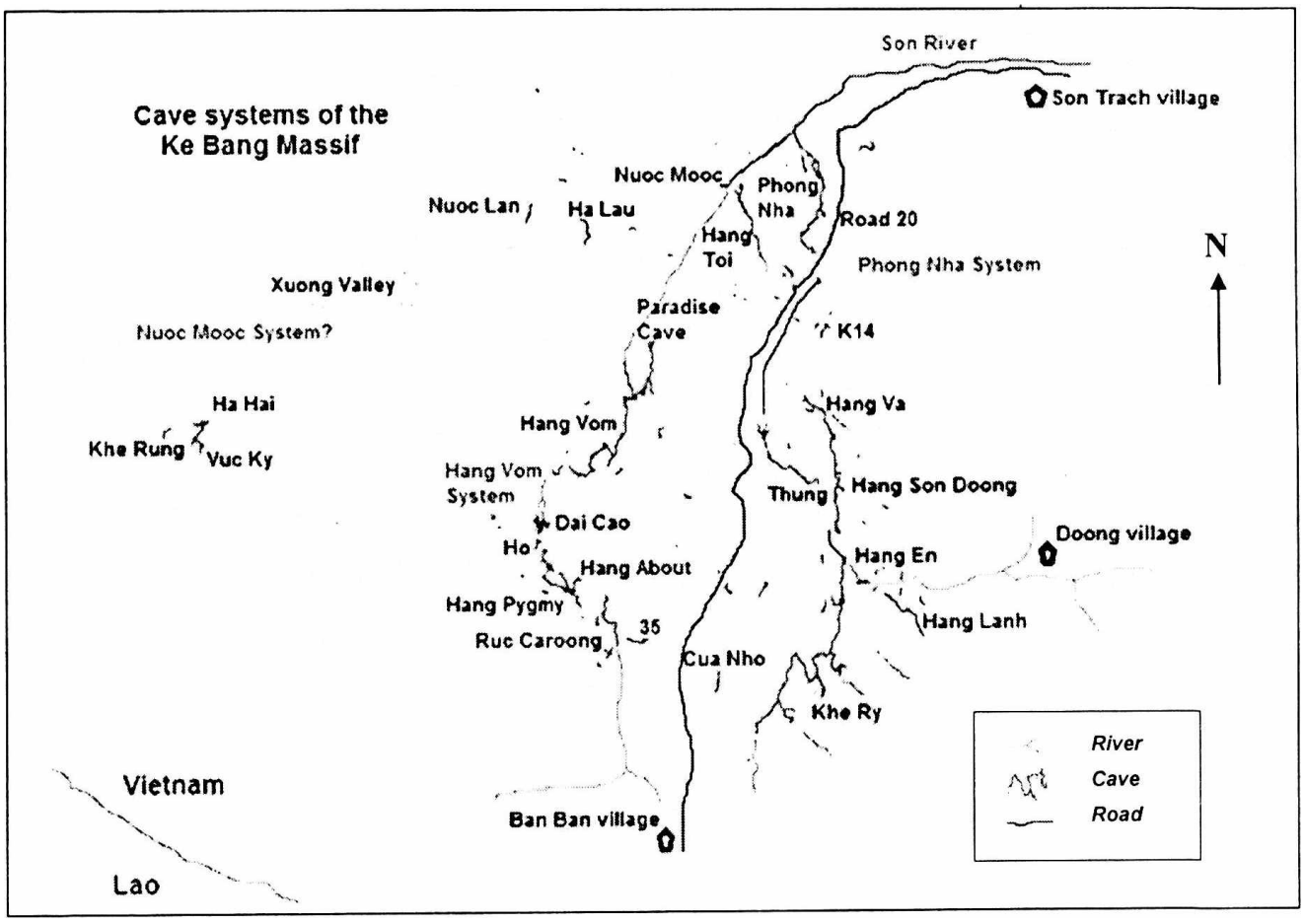



Figure 2. Cave systems of Phong Nha - Ke Bang massifs.

*c) Types of caves*

In terms of morphology, most of the caves are high, wide, and generally linear. Some caves are fairly complex plane maps such as Maze Cave *(fig. 3)*. Cross-section of passages allows classification such as phreatic or vadose (the cave is divided by type of relationship with the regional water table) and develops over many cycles.

Phreatic passages are formed when the cave is beneath the water table, and vadose passages by active stream entrenchment above the water table. There is also undoubtedly paraphreatic development, with caves having an air surface under low flow conditions, when drainage is within the capacity of the system, but reverting to phreatic (water-filled) development under conditions of high flow such as in the wet season when very high levels of rainfall are seen.

Multiple cycles of cave development are also reflected in the cave floor level as well as the entrance level of caves.

In the caves there is extensive distribution of stalactites, stalagmites, columns, and flowstone, with beautiful colors and shapes. There are also many unusual formations such as Phytokarst, Conulites and Stromatolites.

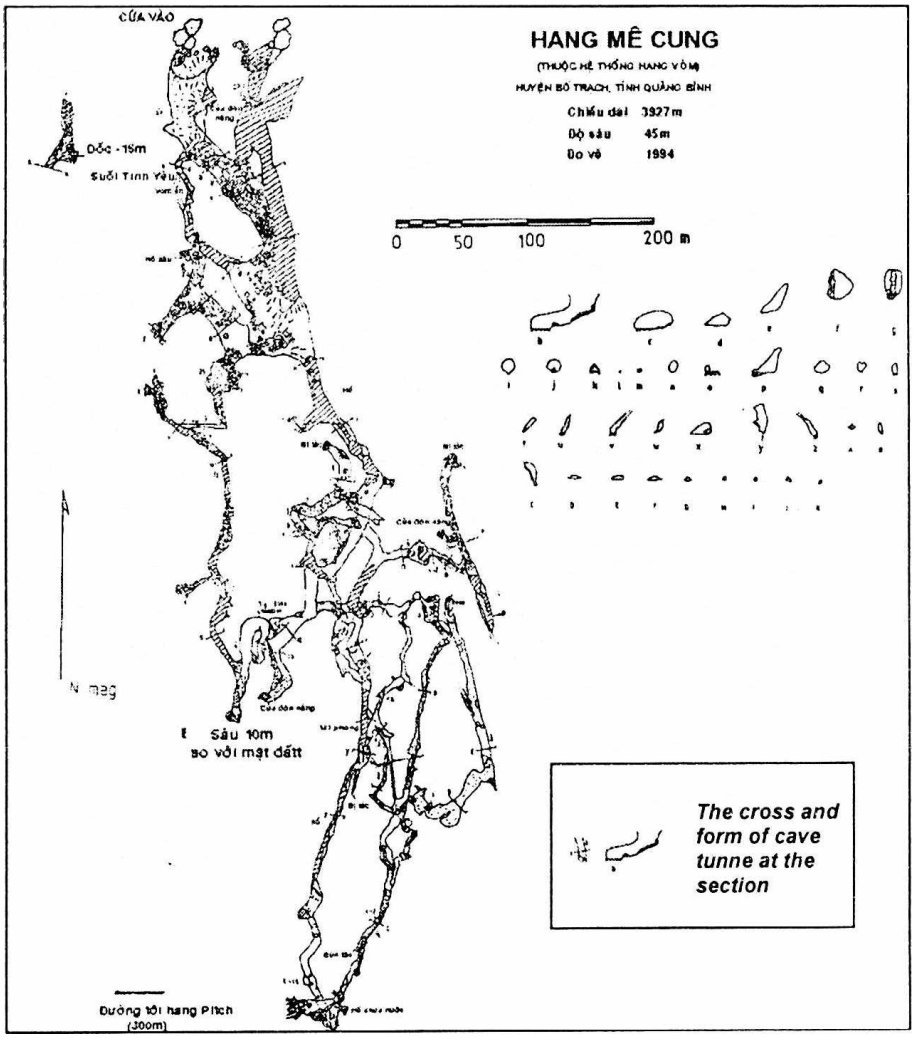



Figure 3. Map of Maze cave [11].

The cave floor of En, Khe Ry, Dai Cao, also shows the mechanical distribution of sedimentary debris such as pebbles, sand and clasts bound by lime cement.

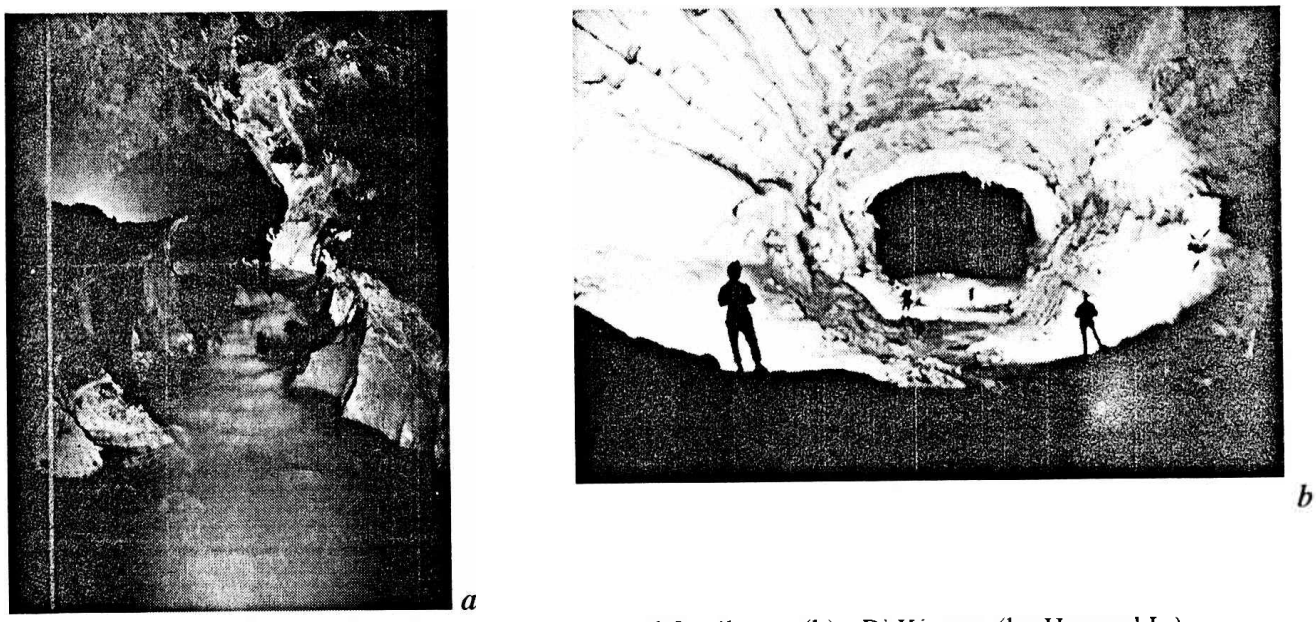
The study results show that the caves can be divided into two kinds in the blocks of Phong Nha - Ke Bang: active caves and fossil caves *(fig. 4)* [12, 13].

The active caves are the river caves mentioned above and are the lowest level in the caves, and still associated with groundwater (aggressive base level) at present.

The fossil caves are divided into:

- The ancient phreatic cave now abandoned by the curent water table. In the cave there are many beautiful stalactites in evidence, such as Phong Nha dry cave. These caves are mainly distributed at a higher level. In some high level caves traces of occupation by ancient people (such as bone, animal teeth, shells, pottery shards, etc.) have been observed.

- The old karstic foot caves are the horizontal caves formed when the foot of the limestone blocks was submerged in water. In the area of Phong Nha - Ke Bang, in these caves there are almost no stalactites. These caves are found at the second level, typically Chay cave (or Xa Phong cave), Wine Factory cave (local name of the cave is unknown).



*a* *b*

Figure 4. Active cave (a) - Son Doong cave; and fossil cave (b) - Bi Ki cave (by Howard L.).

Most caves have complex structures consists of many branches, each branch consists of several passages or chambers. Changes in size may be seen at different levels of cave and the caves have a very large range of passage size from 10 to 40-50m in width and 10-20-50-70 to 80m height ... In each cave, 2 to 4 cave levels were observed. The most obvious is the cave survey in Bo Trach district as Toi, Vom, Phong Nha caves.

The lowest cave level is the river cave level associated with an aggressive base current of the river in the highly active areas. Due to the ability to remove water soluble carbonate and the intensity of the active underground river large cave formation will be at the river level.

Many underground river sand beaches are formed in the cave (Phong Nha, Toi, Khe Ry, Hang En ...) *(fig. 5)*.

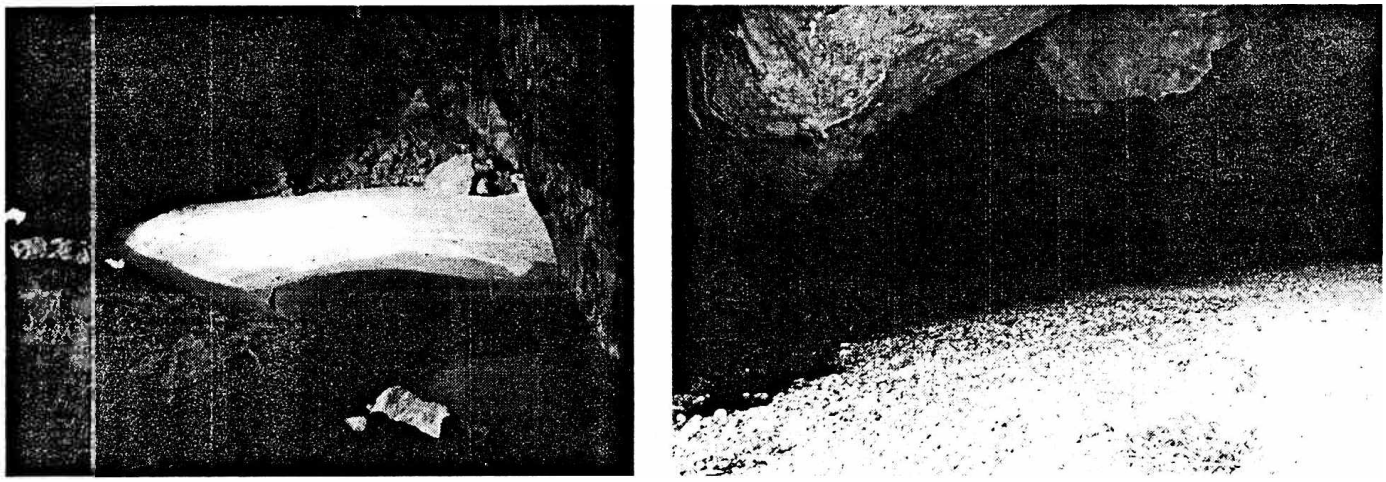


Figure 5. Sand and gravel beaches in En cave (by Nguyen Hieu).

Caves in levels 2, 3 and 4 are the dry caves, highest distribution in the 10 - 15m, 40-50m, and 80-100m levels. The extensive calcite deposition has produced spectacular caves.

The large-sized cave, steep cave floor and activities of the saturated zone frequently vary depending on the season.; in many of the cave creating rapids, the rushing water makes passing some sections very difficult, such as the middle and upper Phong Nha cave.

Some fairly deep sumps through two cave levels are noted and researched in the caves Vom and Ruc Caroong.

Roof collapse often creates large rocks, as observed in dark cave. These breakdown hills may be removed by dissolution and abrasion in time. Large phreatic passages will show a curved or dome-like roof and be fairly wide. Passages of vadose origin will be narrower and more trench-like.

*d) Son Doong cave-the World's biggest cave*

Son Doong cave is formed because of stream capture along a pre-existing N-S trending fault *(fig. 2 & 6)*. The capture likely occurred due to breaching of a different NE-trending fault that blocked water flow until sometime during the Pliocene to latest Miocene (2-5 My). The cave today takes an estimated peak annual discharge of 400-450 m3/s, consistent with a drainage area of 200 $km^2$. At 80-by-80 meters in most places, the Son Doong cave beats out the previous world-record holder, Deer Cave in the Malaysian section of the island of Borneo. Deer Cave is no less than 91-by-91 meters, but it is only about 1.6 kilometers long. By contrast, explorers walked 7 kilometers into Son Doong cave.

The appearance of the collapsed dolines and the along with vegetation appear in the cave have brought the difference of the Son Doong *(fig. 8)*. Causes the appearance of the hole collapsed because in this position the thin limestone cave ceiling, and important intersection coincides with the position of the fracture.

## 3. Cave and exploitation - conservation issues

*3.1. Caves of Phong Nha - Ke Bang National Park and the potential scientific value, economic and national security*

The cave has a very special natural environment - low light, high humidity, less

affected by the elements "outside" ..., which form an endemic fauna and flora and there is also the fascination of the mystery 'wild man'. Many caves in the region of Phong Nha - Ke Bang have been discovered, and they are the important natural resources, contributing to the development of tourism and economic development. Some caves have been used for tourism, such as Phong Nha cave, Paradise cave and they actually attract many tourists. Phong Nha - Ke Bang is facing a big challenge to take tourism development to a new level, especially after the discovery of the World's biggest cave - Son Doong - in 2009.

Cave in the mountains of Phong Nha - Ke Bang terrain play an important role in security and defense, as has been well demonstrated in the war against America.

One of the directions for the exploitation and use of the cave is to develop adventure travel. Adventure travel means not just a restful vacation or regular visit, but this is travel for excitement, physical challenge and the experience of remoteness. Completing the tour the traveler will feel a sense of accomplishment and happiness and have many lasting memories. The karst topography, on the surface as deep slot canyons, lofty peaks, or karst valleys with steep sidewalls and thick forest is a natural landscape that is sure to bring travelers the powerful feeling of adventure.

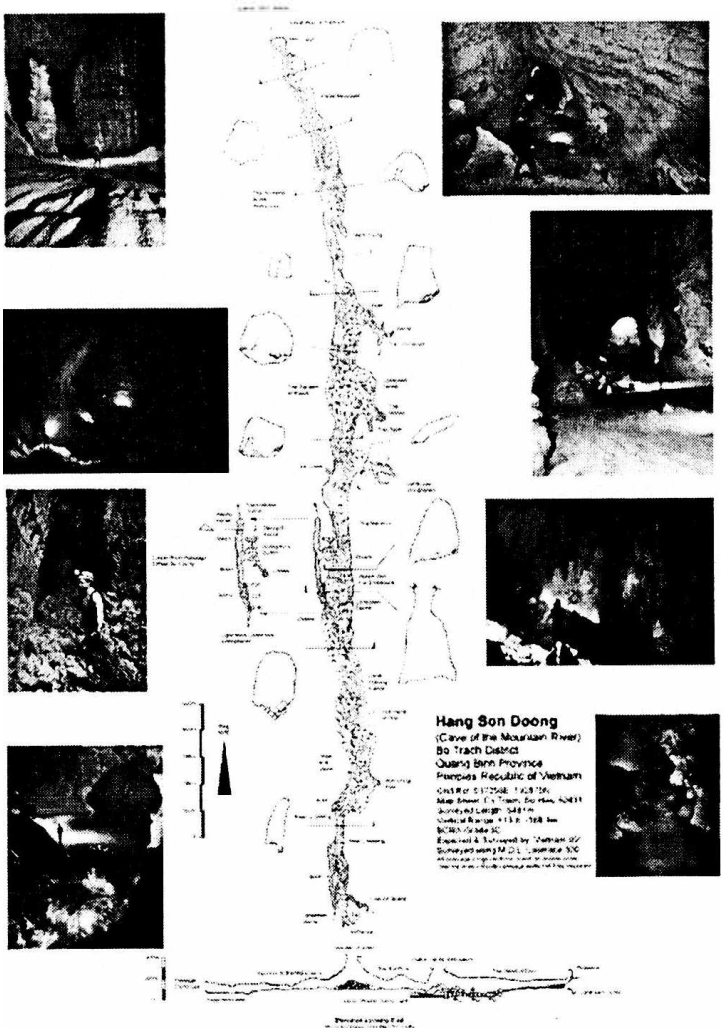



Figure 6. Map of Son Doong cave.

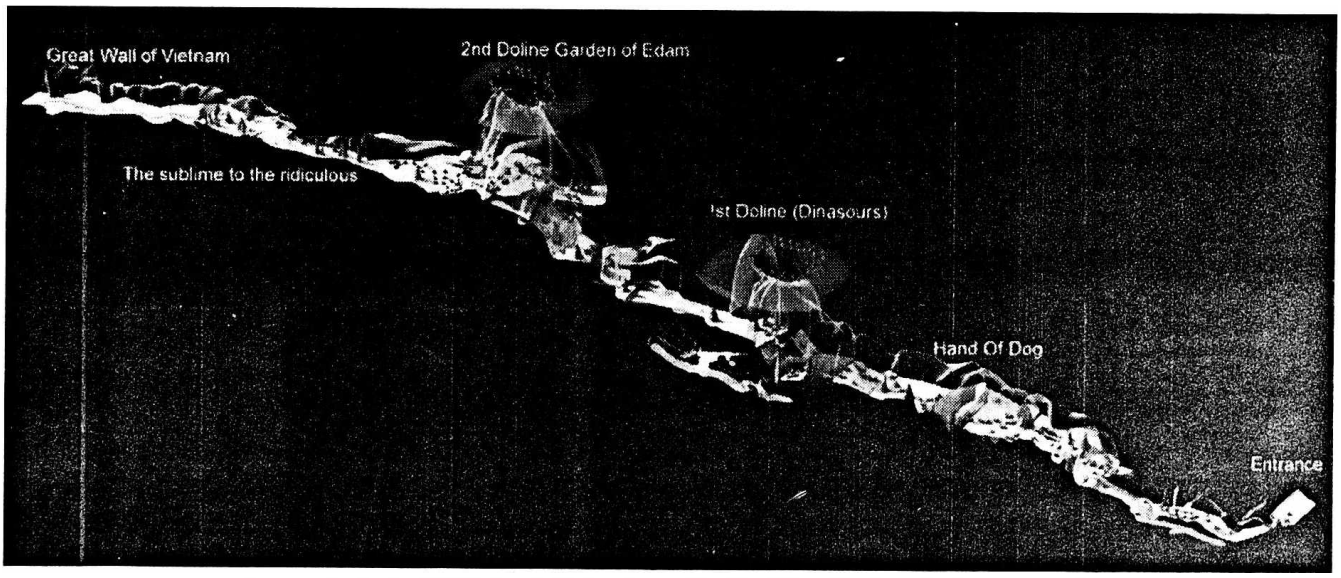



Figure 7. Map in 3D of Son Doong cave (source: National Geographic).

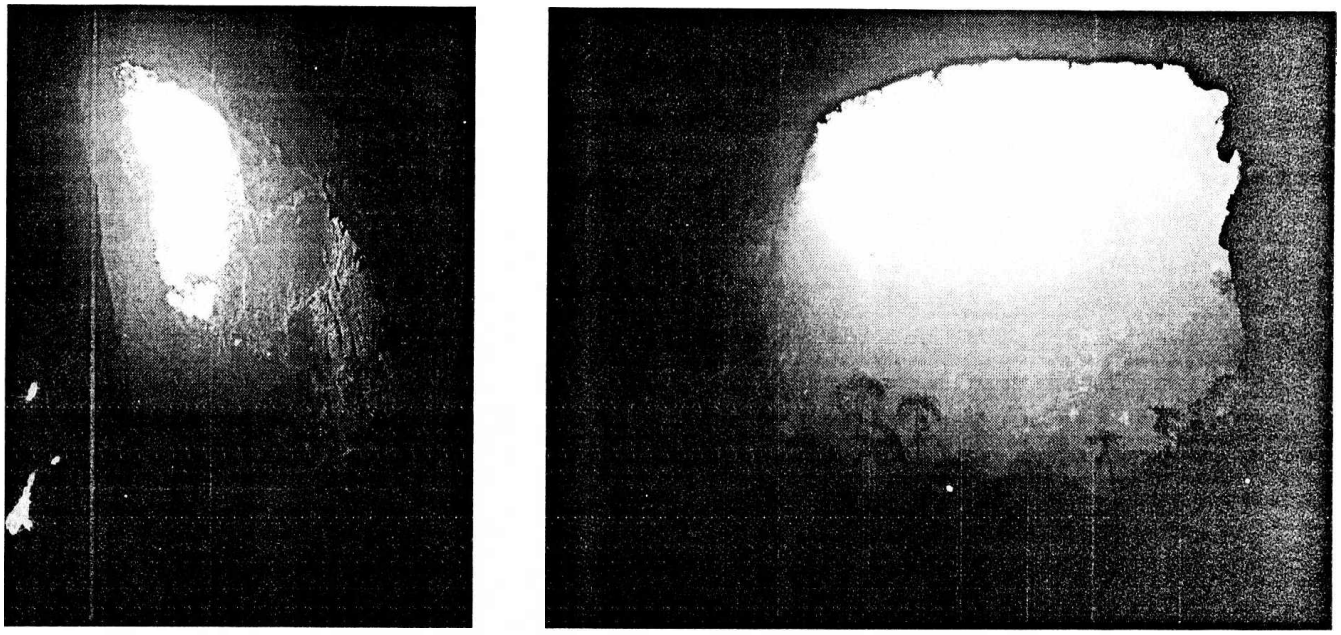


Figure 8. Doline 1 (by Nguyen Hieu) and 2 (by Howard C.) in Son Doong cave.

Current tourism activities of Phong Nha - Ke Bang have no small impact on the caves here. The lighting system in use for a long time have the effect of drying the formations which no longer appear fresh. Also there is the phenomenon of moss and algae growing on the stalactites *(fig. 9, 10)*. Also due to the direct impact of visitors there will be damage to the fossil cave *(fig. 11)* such as impacting of sediments. Some of the layout or irrational displays in the cave also lose aesthetic and natural appeal and a pristine environment.

In addition to the assessment of karst landforms for adventure tourism, it is also necessary to study and assess the non-karst landforms areas, because they form the water basin, creating favorable conditions and difficulties, not to mention particular risks in adventure travel.

*3.2. Recommendations exploitation and conservation*

The cave is an important component, with an independent and intimate relationship with the natural components of the karst area to create a unique environment of the karst region. Therefore, there is a need to manage the cave environment to maintain the karst areas Heritage of Phong Nha - Ke Bang:

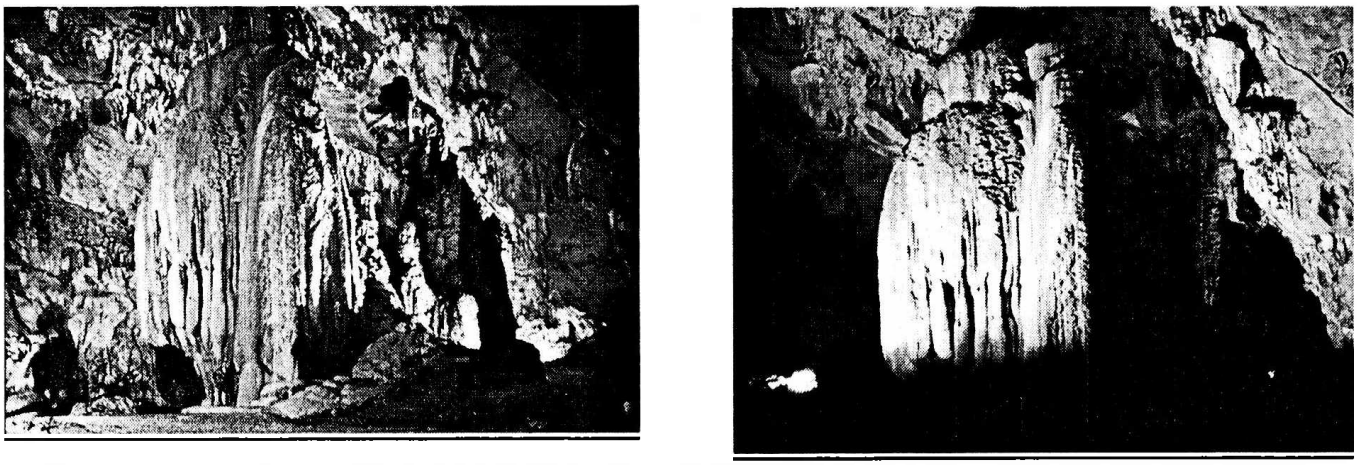


Figure 9. a big fresh stalactite in 1990 (left) (by Howard L.) in Phong Nha cave looks dry and "old" (right) (by Nguyen Hieu) after 20 years of exploitation for tourism.

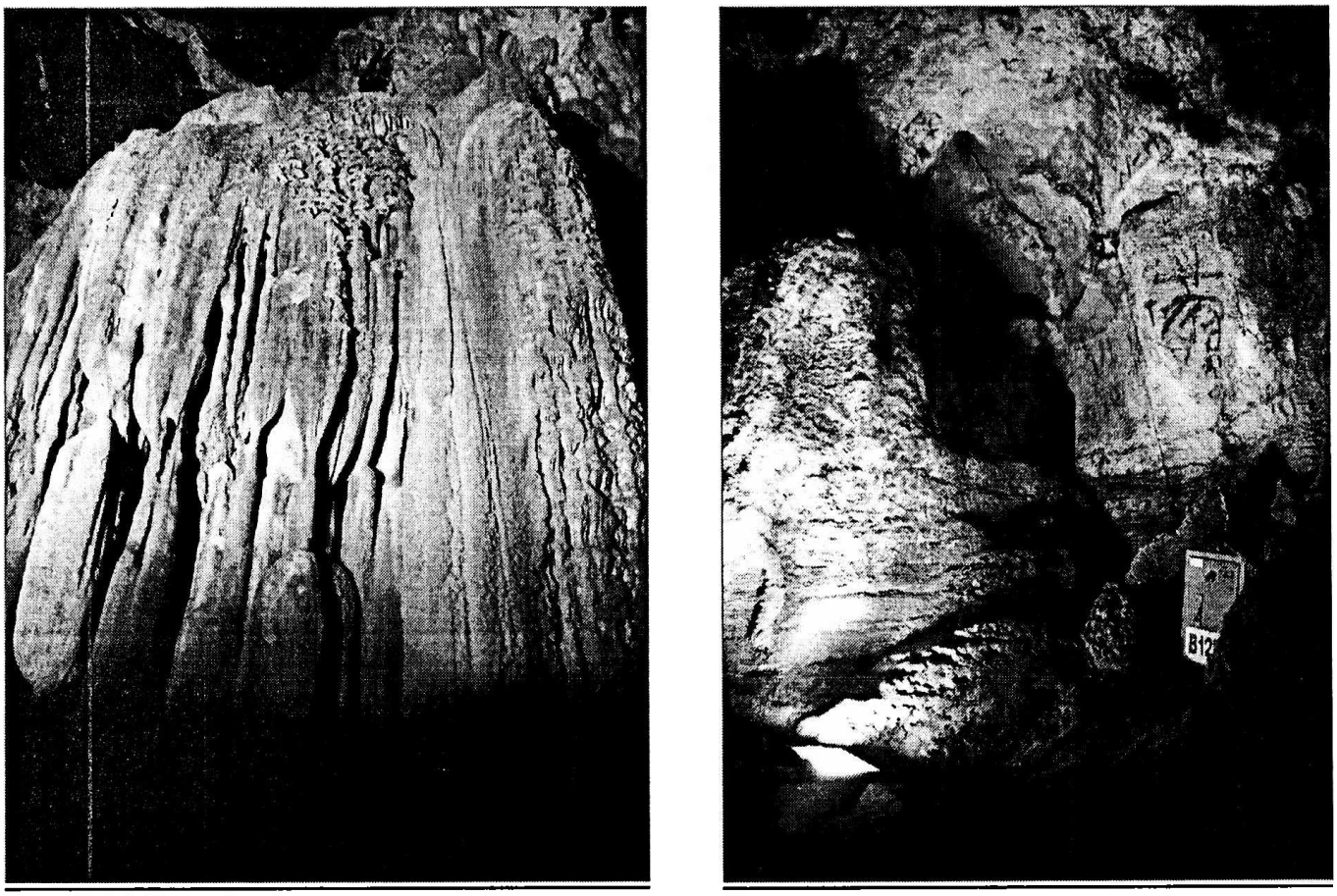


Figure 10. Moss growing on the stalactites in the Phong Nha cave in the position lights (by Nguyen Hieu).

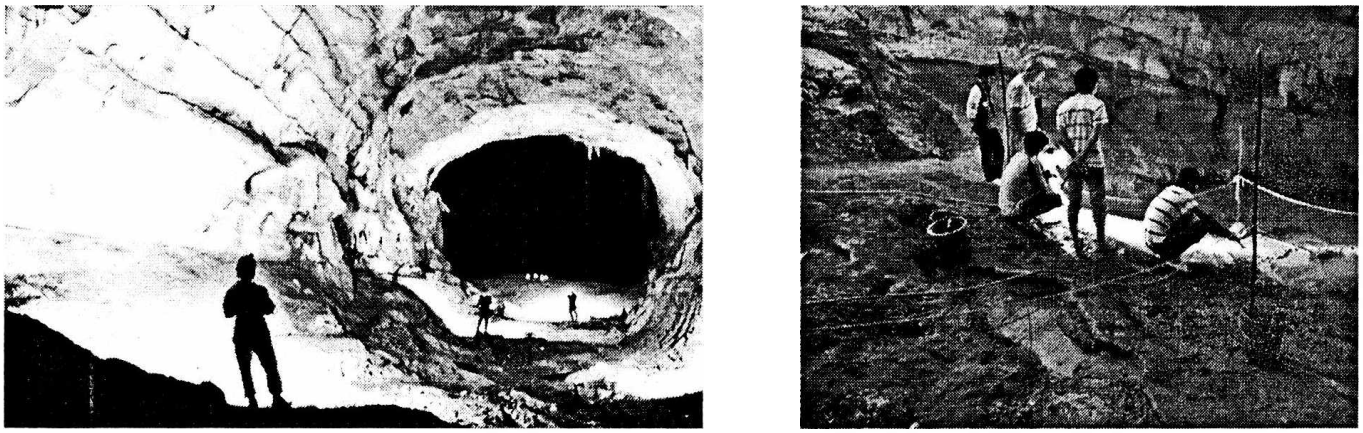


Figure 11. Impact to the cave and inability to restore the fossil cave (Bi Ki cave - a branch in Phong Nha cave) (by Howard L.)

Minimize impact on the environment and landscape of tourists: Limit direct impact on the stalactites, the cave, drilling, and path design not by wood/cement, reduce energy lampenflora.

Create harmony and intimacy with the landscape of the cave: Limit the use of artificial materials, natural shape for the items, do not use light colored lighting.

Pay attention to the safety of visitors: Monitoring of air that affect the health $O_2$, $CO_2$, $SO_2$, $H_2S$, etc., recommended number of passengers, monitoring and timely warning of the areas of potential risk rock fall/ collapse.

Aim to restore the natural environment of the cave, we need to plan "closed" Top periodically to allow the natural environment in the cave to get itself back on track, use of environmental engineering.

Restaurant operators will bring economic benefits, but without careful consideration and appropriate management will do damage to / loss of values many times larger. Therefore, before deciding on further development there should be:

- The overall study, detailed study of the cave (the characteristics of geology, geomorphology, biodiversity, environmental catastrophe risk);

- The development of mining projects in caves must be referred to the judgment and advice of professionals, scientists, as well as extensive consultation of the people and all levels of management,

- Access to "sustainable development,

- Pay attention to the benefits / benefit of the local community.

## 4. Conclusion

World Natural Heritage of Phong Nha - Ke Bang National Park was developed over a limestone block from Devon later (377 million years) and Permian (250 million years). Surrounding limestone blocks development of non-carbonate terrain, provides water collection conditions for development of limestone caves, and at the same time increases the biodiversity in the region.

Great underground cave systems in limestone blocks have been detected and mapped with a total length of 163 kilometers. Most caves here are river caves, interconnected systems made up of three main cave systems: Vom, Phong Nha, and Nuoc Moc systems. The discovery and mapping of these magnificent

cave systems is the effort of government, local people and because of research cooperation between the Faculty of Geography, VNU University of Sciences, and the British Cave Research Association - BRCA.

The cave systems of Phong Nha - Ke Bang are a precious natural resource of the World, Vietnam, and the local community. We can exploit them, using multiple objectives for the conservation and socio-economic development to improve the livelihoods of local communities.

The construction of the development plan for Phong Nha - Ke Bang National Park to 2025 should be completed soon. This must be particularly interested in conservation planning and promoting the values of the Phong Nha - Ke Bang national park; including a focused review of valuable natural areas and proposed protection and controlled exploitation of tourism development, especially the cave systems; control of construction projects to avoid the influence on the natural heritage in core zone and buffer zone. In addition, the general plan should also establish a convenient location, suitable to attract an investment project to build parks, develop eco-tourism, but still preserve the integrity of the natural heritage; enhance infrastructure conditions and social infrastructure to meet operational requirements, National Park protection, and research, improving the living conditions of the population and needs of guests visiting.

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