HNUE JOURNAL OF SCIENCE
Natural Sciences 2025, Volume 70, Issue 4, pp. 182-194
This paper is available online at http://hnuejs.edu.vn/ns
DOI: 10.18173/2354-1059.2025-0065

GEOHERITAGE VALUES OF THE TRANSBOUNDARY WORLD HERITAGE OF PHONG NHA-KE BANG NATIONAL PARK AND HIN NAM NO NATIONAL PARK

Mai Thanh Tan*, Vu Thi Minh Nguyet and Tran Thi Thuy Van
Institute of Earth Sciences, Vietnam Academy of Science and Technology, Hanoi city, Vietnam
*Corresponding author: Mai Thanh Tan, e-mail: maithanhtan@ies.vast.vn

Received August 28, 2025. Revised October 22, 2025. Accepted December 30, 2025.

Abstract. Located on the same karst plateau, Phong Nha - Ke Bang and Hin Nam No National Parks have common characteristics of karst geology, geomorphology, and hydrology. Using a geoheritage approach with field surveys, laboratory analyses, document synthesis, and comparative analysis, the geoheritage's outstanding universal values of Phong Nha - Ke Bang - Hin Nam No have been clarified and supplemented. These values include a long geological and geomorphological evolution from the Middle Cambrian to the Quaternary; the world's largest area of pristine humid tropical karst, featuring a diversity in both surface and subsurface landforms with many global and regional records; and Triassic - Middle Jurassic paleokarst in the form of buried surfaces and filled fissures and caves, a new outstanding universal value unrepresented in the current World Heritage sites.

Keywords: geoheritage, karst, paleokarst, Phong Nha - Ke Bang, Hin Nam No.

1. Introduction

Geoheritage, first introduced in 1993 [1], encompasses global, national, statewide, and local features of geology at all scales that are intrinsically important sites or culturally important sites offering information or insights into the evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference [2]. In Vietnam, geoheritage studies have contributed to the international designation of numerous geosites as World Heritage Sites (WH), such as Ha Long Bay - Cat Ba Archipelago, Phong Nha - Ke Bang National Park, Trang An Landscape Complex, and UNESCO Global Geoparks (GGp) such as Dong Van Karst Plateau, Non Nuoc, Cao Bang, Dak Nong, and Lang Son. However, these results seem to be still modest as many geosites with great potential to become WH or GGp still exist, and even in the internationally recognized geoheritages themselves, numerous values have not been explored. In addition, research on national

and regional geoheritage has received much attention. Thus, research for the designation of international, national, and regional geoheritages and their protection and management needs to be further developed.

Phong Nha-Ke Bang (PNKB) National Park (NP) in Quang Tri Province (Vietnam) and Hin Nam No (HNN) NP in Khammouan Province (Laos) are both located on an intact limestone plateau with a total area of 217,447 ha for the core zone and 295,779 ha for the buffer zone (Figure 1). PNKB NP was recognized as a WH site for its Outstanding Universal Value (OUV) of geology and geomorphology in 2003 and of ecosystems and biodiversity in 2015 [3], [4]. HNN NP also possesses similar values of international significance and is expected to become a WH site. In fact, due to the same geological, geomorphological, and hydrological karst conditions, the geoheritage values of both PNKB and HNN are similar, reflecting the common karst value for this entire limestone massif. The herein presented research clarifies and supplements the geoheritage OUV of the newly transboundary World Heritage site of PNKB NP - HNN NP, which was approved by UNESCO in July 2025.

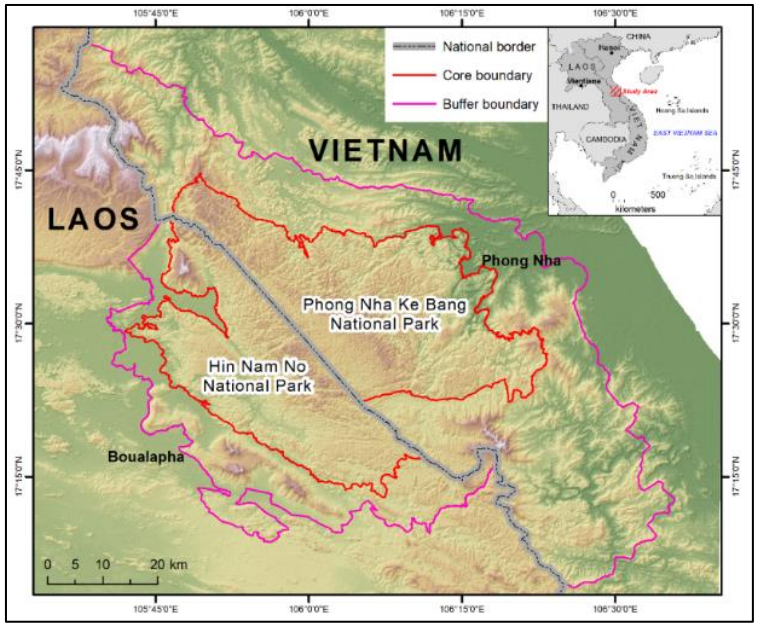

Figure 1. Phong Nha - Ke Bang National Park and Hin Nam No National Park

2. Content

2.1. Research methods

Field surveys, including feature description, measurement, and sampling, were conducted *in situ* throughout the PNKB HNN area for the preliminary assessment of geoheritage values.

Water analyses in the laboratory for basic chemistry (60 samples) and heavy metals (40 samples), combined with field measurements of physicochemical parameters (60 samples), allow the assessment of karst hydrological values.

Synthesis of collected and surveyed documents is a traditional method generally applied in Earth sciences. This is an important basis for determining the geoheritage values of the study area.

Comparative analysis is obligatory for any property nominated as a WH site [5]. Based on the global framework for geological WH [6], the geoheritage values of PNKB HNN are suitable for the theme *Karst and cave systems,* and are compared with 30 karst-related WH sites, especially eight sites in Southeast Asia and adjacent regions.

2.2. Results and discussion

2.2.1. Geological, geomorphological, and karstic hydrological features

Geologically, the study area is located in the structure of the Viet-Lao terrane, belonging to the Indochina composite terrane [7]. Based on reports, geological mapping at a scale of 1:200,000 [8]-[10] and other additional documents [7], [11], the geological formations in the area, composed of metamorphic, sedimentary, and magmatic rocks, ranging in age from the Middle Cambrian to Quaternary, could be summarized as follows (Figure 2).

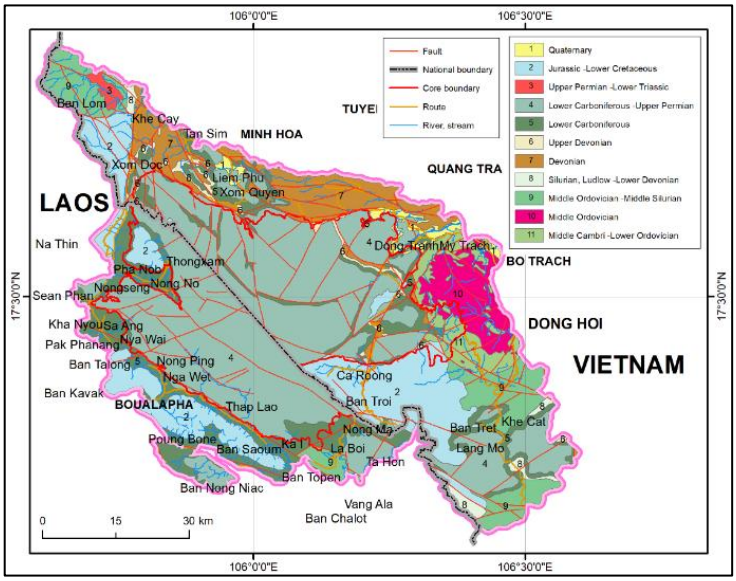

Figure 2. Geological map of PNKB HNN area

(Compiled from [7]-[11])

Middle Cambrian-Lower Ordovician: A Vương Formation ($Є_2$-O_1 *av*): sericite quartzite schist, upwards changing to sandstone, quartzite, sericite schist, and banded black schist.

Middle Ordovician: Vit Thu Lu Complex ($\gamma\delta\ O_2$): biotite granite and granodiorite.

Middle Ordovician - Middle Silurian: Long Dai (O_2-S_2 *lđ*), Song Ca (O_3-S_2 *sc*), and Koduk (O_3-S_1 *kd*) formations: sericite quartz schist, black clay schist, sandstone, and conglomerate, sometimes intercalated.

Silurian, Ludlow - Lower Devonian: Dai Giang ($S_{3\text{-}4}$ *đg*) and Tay Trang (S_4-D_1 *tt*) Formations: sandstone, siltstone, and sericite schist.

Devonian: Tan Lam (D_1 *tl*), Rao Chan (D_1 *rc*), Ban Giang (D_1em- D_2e *bg*), Muc Bai (D_2g *mb*), Dong Tho (D_2g- D_3fr *đt*), and Ngoc Lam (D_3fr *nl*) Formations: sandstone, siltstone, shale, and marl.

Upper Devonian: Xom Nha (D_3 *xn*) Formation: grey and dark grey limestone.

Lower Carboniferous: La Khe (C_1v *lk*) and Boualapha (C_1 *bp*) Formations: siltstone, sandstone, coaly clay, marl, and siliceous limestone.

Lower Carboniferous - Upper Permian: Bac Son (C_1 v^2 - P_2 *bs*), Khammouan (C- P_1 *km*), and Cam Lo (P_3 *cl*) Formations: limestone, covering most of the PNKB HNN's core area.

Upper Permian - Lower Triassic: Truong Son Complex (γP_3 -T_1 *ts*): biotite granite and granite.

Jurassic - Cretaceous: Nam Phouan (J_3 *np*), Mu Gia (J_3 -K_1 *mg*), and Nam Xot (K_1 *nx*) Formations: conglomerate, sandstone, siltstone, and claystone formed mainly in a continental environment.

Quaternary: pebbles, sand, silt, and clay of eluvial, deluvial, proluvial, and alluvial deposits.

Topographically, the PNKB-HNN area is characterized by medium and low mountains and plateaus, of which the central part, an intact karst area covering both cores of PNKB NP and HNN NP, is a strongly dissected plateau. Non-karst reliefs develop on intrusive magmatic, metamorphosed terrigenous, continental sedimentary rocks and unconsolidated deposits, distributed mainly in the outer core zones and in the buffer zones of the national parks. These are the medium and low mountain ranges on which denudation and accumulation processes create various landforms: denudation surfaces at different altitude levels; denuded, eroded, and accumulated slopes; alluvial terraces, and floodplains, etc. The karst reliefs develop on carbonate rocks, which are distributed largely in the core zones and sparsely within small areas in the buffer zones. They include assemblages of tower-like and dome-like karst peaks with karst dolines to different extents. Surface karst landforms are found with all common types, such as karren, tower karst, cone karst, cockpit, doline, shaft, uvala, blind valleys, and polje. Underground karst is very developed, with a system of caves and subterranean rivers at densities among the highest in the world.

In terms of karst hydrology, PNKB HNN is the headwaters of the Xe Bang Fai system, flowing to the Mekong River in the west, and the Gianh River system, flowing into the East Sea in the east. Due to karst characteristics, surface watercourses are sparsely developed, and most rainfall is rapidly absorbed and concentrated into underground rivers in the cave systems. There is a different hydrological regime between the eastern (PNKB) and western (HNN) parts of the area. In PNKB, the main flooding season lasts from September to November, coinciding with the months of heaviest rain; in addition, a minor flooding period falls in May-June. In HNN, the flooding season is earlier than in PNKB, from July to September; watercourses in the dry season dry up with small discharge, or are even exhausted. Notably, due to the nature of the intact calcareous massif and the strong underground karst activities with a complicated system of underground water flow, there may be an exchange of subsurface water between PNKB and HNN.

2.2.2. Geoheritage OUV

Based on new studies and survey results, it can be affirmed that PNKB HNN possesses OUVs on geological and topographical evolution history, karst, and paleokarst values.

**** Long geological and geomorphological evolution***

The dossier for WH inscription of PNKB NP [3], [4] stated that it has a complicated geological structure and a long earth crust development history from Ordovician to the present, with 5 cycles: Late Ordovician - Early Silurian, Middle Devonian - Late Devonian, Carboniferous - Permian, Mesozoic, and Cenozoic. Updating new documents allows us to identify that PNKB HNN, situated in the Viet - Lao terrane belonging to the Indochina composite terrane, has a geological evolution from Middle Cambrian to Quaternary with the following main stages: 1- Middle Cambrian - Silurian; 2- Devonian - Late Permian; 3- Late Permian - Middle Jurassic, and 4- Late Jurassic - Quaternary [7], [12], [13].

The Middle Cambrian- Silurian: related to the assembly and breakup of Gondwana. This process began in the Middle Neoproterozoic, but in the study area, it only occurred from the Middle Cambrian. These are intercalated volcanic and terrigenous rocks ($Є_2$ -O_1 *av*), diorite and granodiorite intrusion ($\gamma\delta$ $O_{2\text{-}3}$), turbidite, pelagic black chert, shallow marine sediments (O_2 -S_2 *lđ*, O_3 -S_2 *sc*, O_3 -S_1 *kđ*), reflecting tectonic context of volcanic arc, back-arc basin, connection of Viet - Lao and Kon Tum terrain along the Tam Ky - Phuoc Son suture, forming Proto-Indochina composite terrane, separating it from the western Australian margin of Gondwana [7], [14].

Devonian- Late Permian: related to the formation of the Pangaea supercontinent. In the study area, Devonian - Lower Carboniferous sediments were formed, such as D_1 *tl*, D_1 *rc*, D_1em- D_2e *bg*, D_2g *m*, D_2g -D_3fr *đt*, D_3fr *nl*, D_3 *xn*. They showed typical transgressive sections from coarse terrigenous sediments upward to terrigenous-carbonates rich in benthos and then siliceous-calcareous turbidites containing abyssal fossils [15]. At the beginning of the Early Carboniferous, uplift movement resulted in the formation of terrestrial basins containing coal rich in plant fossils (C_1v *lk*, C_1 *bp*) [8], [10]. After that, from the end of the Early Carboniferous to Late Permian, carbonate sediments rich in neritic fossils were distributed throughout the region (C_1v^2 -P_2 *bs*, C -P_1 *km* and P_3 *cl*).

Late Permian- Middle Jurassic: related to Indosinian orogeny. In the study area, only a granite intrusion (γP_3 -T_1 *ts*) found in a small area is related to this event. Notably, a Late Permian-Middle Jurassic sedimentary hiatus occurred in the study area. The exposed carbonate rocks underwent karstification. Its products, the karst landforms, were "fossilized" and became "paleokarst" when they were uncomformably covered by younger rocks.

Late Jurassic - Quaternary: related to Indochina extrusion and East Sea extension. In the Late Jurassic - Cretaceous, geological formations (J_3 *np*, J_3-K_1 *mg*, K_1 *nx*) were mainly composed of continental red coarse-grained sediments. The collision between the Indian and the Eurasian plates led to clockwise rotation and extrusion of Indochina, forming a northwest-southeast strike-slip fault system in the Eocene - Miocene; spreading

of the East Sea, forming new oceanic crust in the Oligocene - Miocene [16]. In the study area, strong exogenous activities in the Oligocene led to the formation of a large denudation surface. Due to subsequent neotectonic uplift and erosional dissection, this surface existed only in the form of remnant peaks at an altitude of 1200 - 1600m. Similarly, in the Pliocene, an alternation between strong and relatively stable tectonic activities resulted in the formation of denudation surfaces, preserved today at 400-600 m and 200-300 m elevations of the margin of the limestone massif. During the Quaternary, the marine regression/transgression cycles in the late Early Pleistocene, Middle Pleistocene, Late Pleistocene, and Middle Holocene combined with neotectonic uplift led to the formation of caves and terraces at present in different elevations.

**** Karst***

The PNKB HNN heritage, including 2 NP's core zones, covers an area of approximately 217,447 ha, made up largely of continuous karst (85%). This may be the largest naturally pristine humid tropical karst area in the world. Primary vegetation accounts for 94.25% of the area, while only 5.63% is secondary or impacted vegetation, and a very small proportion of 0.12% is man-made vegetation without residential plant communities. Based on the physicochemical measurements (turbidity, pH, temperature, pH, DO, EC, and TDS), basic chemical analyses (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO^{-}, Cl^{-}, NO_3^{-} and SO_4^{2-}) and heavy metal analyses (Cu, Pb, Zn, Mn, Cd, Hg, As, and Fe), hydrogeochemistry of water in the area is typical of a karst environment with major components of Ca-Mg-HCO_3 and Ca-HCO_3. Water quality is hardly impacted by human activities (Table 1). These results are relatively consistent with the study by Ponta *et al.* [17] showing that the karst hydrological value is still pristine.

Table 1. Basic chemical analysis for water sampled from PNKB HNN (Unit: mg/L)

National Park	Values	Criteria							
		K^{+}	Na^{+}	Ca^{2+}	Mg^{2+}	HCO_3^{-}	Cl^{-}	NO_3^{-}	SO_4^{2-}
HNN	Min	0.08	0.39	26.05	1.79	91.5	2.81	0.12	2.20
	Max	0.73	3.31	100.2	30.4	381.25	4.37	7.83	5.36
	Mean	0.40	1.60	51.50	5.90	180.10	3.80	2.20	3.20
PNKB	Min	0.27	0.87	3.51	0.61	9.76	3.12	0.1	2.20
	Max	2.59	5.15	75.15	18.54	265.35	9.98	4.74	12.13
	Mean	0.80	2.34	38.20	4.46	131.78	4.99	1.80	4.21

The karstification process has created a very diverse, complicated, and unique landscape: from deeply dissected mountains and plateaus to large, closed, flat-bottomed valleys. Surface karst landforms here are abundant and diverse, with most types in the world, such as karstified denudation surfaces, karst tectonic scarps, conical karst, tower karst, karren, polje, sinkholes, ponors, cenote springs, and uvala. Most remarkably, in HNN, a polygonal karst has developed like a giant egg tray with countless deep depressions (cockpits) surrounded by conical remnant hills (fengcong), spreading over a large area that has never been seen in any other WH site [18].

Underground karst in PNKB HNN is very developed, with cave systems of high quantity and density in the world. So far, about 600 caves have been discovered, and this number will continue to increase in the future. Due to neotectonic faulting and uplift, the caves found here are quite diverse, such as river caves, dry caves, terraced caves, suspended caves, dendritic caves, and intersecting caves. Additionally, these caves possessed abundant, diverse, and unique speleothems with most types in the world. Many caves hold world or regional records, such as Son Doong - World's largest cave with many landscape records [19]; Va Cave with the world's most unique, beautiful, and homogenous forest of stalagmite towers [19]; Son Oxalis Cave with a unique coralloid chamber never seen in any cave in the world [19]; Thien Duong recognized as "The cave with the most unique and magnificent stalactite and stalagmite system in Asia" by the Asia Book of Records; Xe Bang Fai, a large cave with abundant speleothems, including many large and magnificent stalagmites, flowstone draperies, cave pearls and gour pools measuring up to 61 m, the world's largest documented gour pool formed in caves [20] and the flood discharge among the world's largest karst springs [21]; Thap Lao Cave with paleokarsts, and paleo-cave formed in the Triassic - Middle Jurassic [22].

**** Paleokarst***

Paleokarst is a karst relief formed in the geological past and buried by younger sedimentary rocks. It was observed in HNN at Phou Chang Mount and in Bancony passage of the Xe Bang Fai Cave [18], [23]. Field surveys, stratigraphic comparison, and petrographic thin-section analysis of carbonate and clastic sedimentary rocks confirm the existence of paleokarst in both PNKB and HNN in the form of buried surfaces (karren and polje) and filled fissures and caves [22].

Buried paleokarst was observed at outcrops in the northern and southern margins of PNKB NP. The most typical exposure, at Km 133+350 QL12, about 8.5 km from the Cha Lo border gate (Figure 3), showed a paleokarst surface as the unconformable boundary between Upper Devonian thinly bedded black limestone of Xom Nha Formation (D_3 *xn*) and Upper Jurassic - Cretaceous red siltstone of the Mu Gia Formation (J_3 -K *mg*). This buried paleokarst was a relatively smooth karren with a height difference of 10-20 cm between round-top ridges and shallow grooves, reflecting a relatively long karstification and Kast in the final stage of evolution.

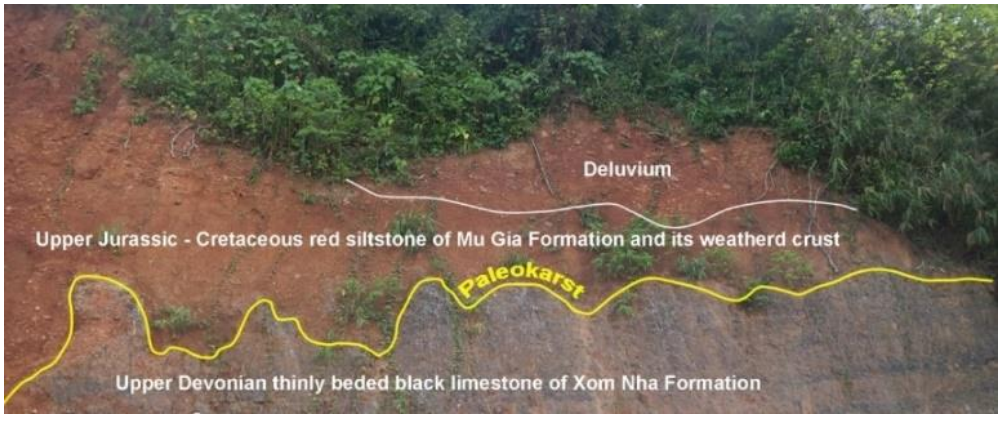

Figure 3. Buried paleokarst at Km 133+350 QL12 [22]

Filled paleokarst was most commonly encountered in the study area. In HNN, it was encountered in many exposures as limestone fissures were filled with red siltstones, sandstones, or red-cemented breccias, for example, near Pak Tham cave, Ban Dou, Pa Khoong cave in the northwest, Thap Lao area in the middle buffer zone, and even in bared karst of Sam Nang in the core zone. In PNKB, similarly filled paleokarst was found on the ceiling, walls, and floor of some caves such as Ca Rung, Ruc Mon, Son Doong, Nuoc Nut, and Nuoc Lanh. Among the filled paeokarsts, Thap Lao and Noong Ma caves (Figure 4) were the most notable. They were the caves on Carboniferous - Lower Permian limestone of Khamouan Formation (C-P_1 *km*) filled by Upper Jurassic red siltstones or red-cemented breccias of Nam Phouan Formation (J_3 *np*) in Thap Lao or by Upper Jurassic - Lower Cretaceous banded gray sandstones and siltstone of Mu Gia Formation (J_3-K_1 *mg*) in Noong Ma cave. These caves, as well as other filled paleokarst, might have been formed in Triassic - Middle Jurassic, the sedimentary hiatus period in the study area.

Figure 4. Filled paleokarst: paleo-caves filled with red-cemented breccias in Thap Lao (left); banded gray sandstones and siltstones in Noong Ma (right)

Paleokarst discoveries in the study area allow confirmation that the uniform evolution of the karst landscape throughout the entire PNKB HNN area started in the Triassic, when the limestone massif, earlier formed in a marine environment, was raised out of the water surface and subjected to solution shaping karst landforms. This karstification was related to the Late Permian-Triassic unconformity, encountered not only in this area but also in many places in Southeast Asia, such as Thailand, Laos, Cambodia, Vietnam, and South China [24]. The karstification finished by the end of the Middle Jurassic, when the region subsided and was covered by Upper Jurassic - Cretaceous sediments. As a result, paleokarsts in this region were dated from the Triassic to the Middle Jurassic. This discovery allows us to determine the age of the caves in PNKB HNN, the oldest being Triassic - Middle Jurassic, much older than suggested by previous studies [3] [4], with the oldest age of Oligocene for the Khe Ry cave.

In terms of geoheritage, it is worthy to consider international significance and OUV of paleokarst. So far, there have been 30 WH sites related to karst and cave systems. However, Palaeokarst properties that contain important stories about past conditions on Earth are not explicitly represented on the World Heritage List, although several World Heritage karst properties contain caves with excellent paleoclimate archives [25]. Thus, a heritage site with important paleokarst characteristics is very likely to become a WH site.

**** Comparison of geoheritage values of PNKB HNN with other WH***

To determine the geoheritage's OUV of PNKB HNN, it is necessary to have a comparative analysis of this value with 30 present karst-related WH sites, including: 8 heritage sites in the Southeast Asia region and its vicinity, 22 others in the Asia–Pacific region (4), Europe and North America (14), Africa (2), Latin America-Caribbean (1). The WH sites outside Southeast Asia and its vicinity are very different from the PNKB HNN karst because it is not a humid tropical karst but a temperate, subtropical, arid climate karsts and the bedrock is dolomite, sandstone, evaporite sediments - gypsum; some WH sites are also affected by glaciation.

At the regional level of Southeast Asia and its vicinity, PNKB HNN is compared with eight WH sites (Table 2). In terms of area, PNKB HNN (217,447 ha) ranks third among these WH sites, after Lorentz National Park (2,350,000 ha) and Purnululu National Park (239,723 ha). However, these two sites do not represent humid tropical karst; Lorentz National Park has a climate ranging from tropical alpine glaciers to lowland tropical rainforests, while Purnululu National Park has a hot, dry tropical savanna climate. As a result, PNKB HNN karst can be the largest pure tropical karst. PNKB HNN and most others have a karst formation process on limestone, which is quite different from Purnululu National Park, with a fluviokarst process on sandstone. Among WH sites related to limestone karstification, only PNKB HNN, Ha Long Bay - Cat Ba Archipelago, and South China Karst developed on Devonian - Permian limestone, the others on Miocene, except for Trang An Scenic Landscape Complex on Triassic. Although all are developed on Devonian - Permian limestone, Ha Long Bay - Cat Ba Archipelago shows tropical tower karst eroded by the sea, South China Karst presents subtropical karst evolution, and PNKB HNN karst expresses tropical monsoon karst in an area with a long geological and geomorphological evolution history from Cambrian to Quaternary.

Table 2. Karst-related WH in Southeast Asia and its vicinity

No.	WH name – State Party (Inscribed)	Area Environment	Key karst features
1	Ha Long - Bay Cat Ba Archipelago – Vietnam (1994, 2000, 2023).	65.650 ha Humid tropical monsoonal environment.	The world's most extensive and best-known example of tropical tower karst invaded by the sea. The world's most important areas of fengcong (clusters of conical peaks) and fenglin (isolated tower features) karst. Devonian - Permian limestone.
2	Trang An Landscape Complex - Vietnam (2014).	62.26 ha Humid tropical monsoonal environment.	Example of transition of cone karst (fengcong) to tower karst (fenglin) near baselevel. Numerous navigable foot-caves through towers. Freshwater swamp notches give way to intertidal marine notches near the coast. Triassic limestone.

3	South China Karst – China (2007, 2014).	97.125 ha Subtropical humid monsoonal environments from the interior plateau to progressively more lowland conditions.	Serial WH sites with seven components representing the complex evolution of the world's most outstanding karst landscape: Shilin comprises stone forests on an undissected plateau; Jinfoshan shows the first stage of plateau dissection with high abandoned caves; Wulong is dissected plateau karst with spectacular tiankeng, natural bridges and gorges; Shibing reveals the different expression of fengcong valley karst when developed in dolomite; Libo and Huanjang provide superb examples of extensive forested cone karst (fengcong and fenglin), poljes, gorges and caves; Guilin shows fengcong along the Li River gorge and impressive fenglin tower development on neighbouring riverine plains. Carboniferous - Permian limestone and dolomite.
4	Gunung Mulu NP - Malaysia (2000).	52.864 ha Humid tropical rainforest.	Large underground rivers with lengths of over 290 km, including the world's largest underground room (Sarawak Chamber), major speleothem deposits, and 1.5 million-year sediment sequences. Surface features include giant collapse dolines and spectacular razor-sharp pinnacle karst. Miocene limestone.
5	Puerto Princesa Subterranean River NP - Philippines (1999).	22.202 ha Humid tropical rainforest.	Tropical karst landscape: polygonal karst, towers, and polje. A major underground river drains directly to the sea; the lower portions of the cave are tidal and navigable for 6 km. Miocene limestone.
6	Lorentz NP - Indonesia (1999).	2.350.000 ha Tropical glaciated alpine to lowland tropical rainforest.	Continuous transect from snow caps (5030 m) to the tropical coast. Huge sinking rivers and springs. Miocene limestone.
7	Purnululu NP - Australia 2003.	239.723 ha Tropical savannah regime.	Outstanding example of quartz sandstone fluviokarst with beehive-shaped hills separated by narrow sinuous gorges. Devonian quartz sandstone.

8	Rock Islands Southern Lagoon - Palau (2012).	100.200 ha Humid tropical environment.	A superb example of partly drowned cone karst. 445 islands, mainly at elevations of 10-100 m above sea level. 52 marine lakes occupy partly drowned karst depressions (cockpits) with passages connecting to the sea. Miocene coralline limestone.
9	PNKB HNN *PNKB NP part (2003, 2015).*	217.447 ha Humid tropical monsoonal environment.	Strongly dissected vast plateau. Diverse landscape with unique and varied surface landforms of mostly tropical karst types. Very developed subsurface karst with the cave systems of high quantity and density in the world. Caves and speleothems diversified in size and type, with many worldwide and regional records. Devonian - Permian limestone. Long geological evolution from the Cambrian to the Quaternary. Triassic - Middle Jurassic paleokarst.

Based on William [18], AndAnd McKeever et al. [6]

In general, the PNKB HNN karst shares common characteristics with other karst WH sites in Southeast Asia and its vicinity due to strong surface and underground karstification in a humid tropical environment. However, there are also differences due to the bedrock (age, purity, tectonic activity, fissures, distribution area), morphology, and landform diversity. The prominent differences of PNKB HNN include: The largest humid tropical karst area; Diverse karst landforms in types, sizes, and morphologies both on the surface and underground with records recognized at the world and regional levels; The oldest limestone bedrock in the region (Devon - Permian) and long geological evolution (Middle Cambrian - Quaternary); and Triassic-Middle Jurassic paleokarst not mentioned in any WH site.

3. Conclusions

PNKB and HNN National Parks are both located on an intact limestone massif and possess the same geoheritage of geological, geomorphological, and karstic hydrological values.

A long geological and geomorphological evolution lasted from the Middle Cambrian to the Quaternary with four stages: (1) Cambrian-Silurian volcanic arc, and back-arc basin; (2) Devonian-Late Permian coastal, neritic and abyssal environments; (3) Late Permian-Middle Jurassic paleokarst formation; (4) Late Jurassic-Quaternary formation of continental sediments and present observed landforms.

The naturally pristine karst is ranked as the world's largest humid tropical karst. The landscape is diverse with unique and varied surface landforms of mostly tropical karst types. Subsurface karst is highly developed, with a high quantity and density of cave

systems in the world. Caves and speleothems are diverse in size and type, with many worldwide and regional records.

Paleokarst, found in the form of buried surfaces and filled fissures, developed uniformly throughout the whole PNKB HNN area from Triassic to Middle Jurassic. This discovery allows us to determine that the age of the caves is much older than previously recognized. Paleokarst is a new OUV, unrepresented in the current WH list.

The above-mentioned geoheritage values are distinct from the OUV of the current karst-related World Heritage sites. The outstanding universal values of the new transboundary World Natural Heritage site of Phong Nha–Ke Bang and Hin Nam No should be appropriately utilized, effectively managed and sustainably conserved.

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