



GEOLOGICAL - GEOMORPHOLOGICAL VALUES AND CONSERVATION, THE WORLD'S NATURAL HERITAGE OF HA LONG BAY, QUANG NINH, VIETNAM

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Abstract

Ha Long Bay is a World Natural Heritage site of Vietnam, recognized twice by UNESCO in 1994 and 2000 for its outstanding geological and geomorphological values, particularly its unique limestone topography, prominent karst islands, and caves above and below sea level. Currently, some islands and caves have been severely affected by erosion, collapse, and chemical corrosion caused by waves and seawater, which impacts the beauty of this natural heritage. The results presented in this paper provide additional information for managers in support of conservation efforts.

Keywords: Ha Long Bay; World natural heritage; Thien Cung cave; Ga Choi island.

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1. Introduction

Ha Long Bay is located in Quang Ninh province, in the Northeast of Vietnam, with geographical coordinates ranging from 107.00 to 107.30° E and 20.75 to 20.95° N (Fig. 1). It covers an area of 1.553 km² and includes 1.969 islands. This is one of the world's most famous and beautiful marine areas, featuring stunning natural landscapes and unique, diverse ecosystems, with great potential for tourism development.

On December 17, 1994, at the 18th session held in Phuket (Thailand), the UNESCO World Heritage Committee officially recognized Ha Long Bay as a World Natural Heritage Site for its magnificent natural landscape and high aesthetic value.

On November 29, 2000, UNESCO granted Ha Long Bay a second recognition as a World Heritage for its exceptional global value in geology, history, and karst geomorphology, under Criterion (viii) of the Convention.

Many researchers have studied the geological, geomorphological, and landscape values of Ha Long Bay [3, 10, 11, 12, 14]. However, these studies have not addressed the risks of natural hazards or the conservation of the heritage landscape. In this paper, the authors provide an overview of the outstanding geological, geomorphological, and landscape values of Ha Long Bay and highlight the current situation to propose effective conservation solutions.

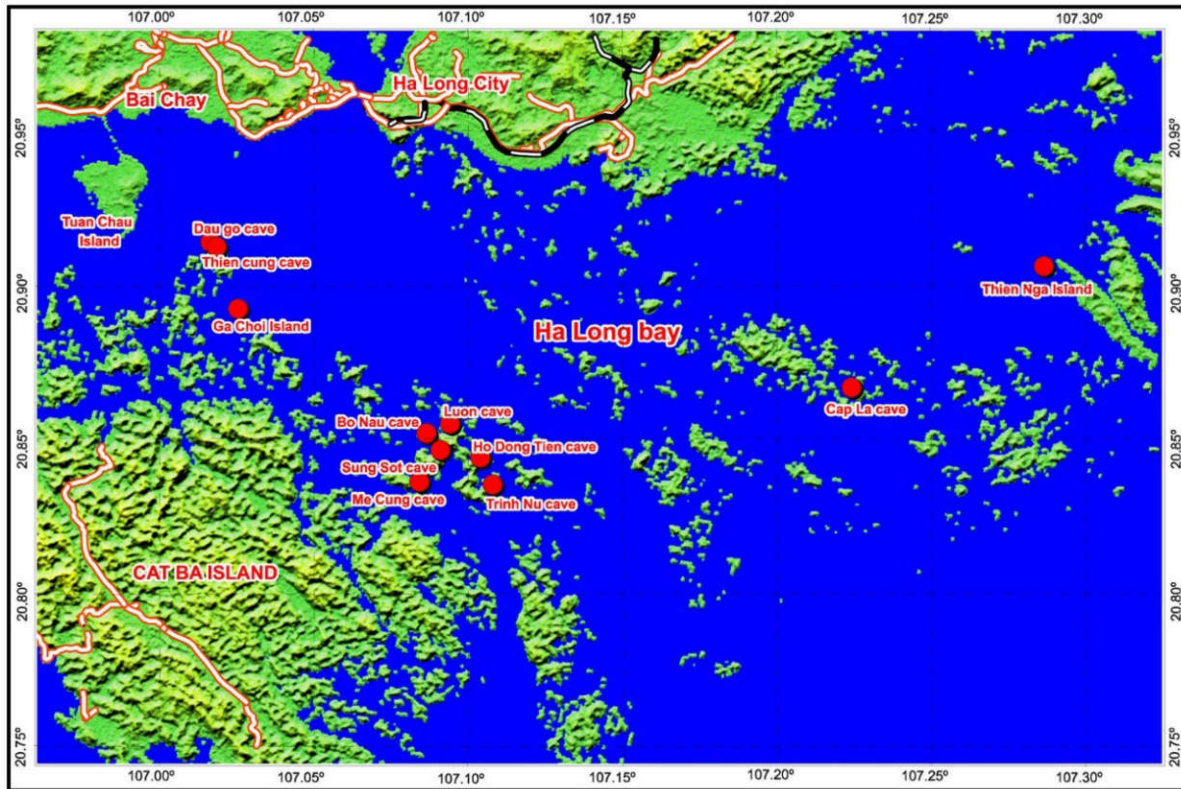


Figure 1: Location map of survey sites in Ha Long Bay

2. Characteristics of topography and geomorphology in Ha Long Bay

2.1. Material and evolution of Ha Long Bay

Ha Long Bay was formed 7,000 - 8,000 years ago from ancient seas that had accumulated limestone layers over a thousand meters thick, originally deposited around 340 - 250 million years ago during the Carboniferous-Permian period. These layers underwent a karst erosion phase lasting over 20 million years in a continental environment during the Neogene and Anthropocene epochs, associated with global warming and ice melting [6, 12].

The limestone in Ha Long Bay is dolomitic, light gray, and belongs to the Bac Son Formation (C_1 -P *bs*), as determined by paleontological analysis of mosses, foraminifera, rays, corals, crinoids, and brachiopods [12].

2.2. Characteristics of topography

Ha Long Bay has two main types of islands: limestone islands and schist islands, which are primarily distributed in the southeast of Bai Tu Long Bay and the southwest of Ha Long Bay. According to statistics from the Bay Management Board, out of the total 1,969 islands, 1,921 are rocky islands with an average elevation of around 200 m. The topography of these islands was formed through tectonic uplift and subsidence processes that occurred approximately 250 to 280 million years ago. Due to the effects of ocean waves, the dissolution of limestone, and other external factors, the limestone islands have developed into a variety of unique shapes, rising above the sea surface and contributing to the majestic landscape of Ha Long Bay.

2.3. Characteristics of geomorphology

Ha Long Bay is located in the northwest of the Gulf of Tonkin, bordering the coastal areas of Quang Ninh and Hai Phong. This region features coastal mountainous terrain, particularly limestone islands with prominent karst characteristics, including both above and below-sealevel formations that give rise to typical karst landscapes and cave systems.

Under hot and humid tropical climate conditions, heavy rainfall, slow neotectonic uplift, and strong wave action, the geomorphology of the limestone islands in Ha Long Bay has evolved into a perfect example of mature karst development.

The karst evolution process on limestone islands from the Miocene period to the present has gone through 5 stages: 1- Creation of ancient plains, 2- Formation of karst funnels and valleys, 3- Formation of clusters of conical hills linked together (called fengcong in China), 4- Development into tall stone towers with vertical, separate walls (fenglin) [11, 14].

3.2. Data

Data collection from the field survey.

Table 1. Survey locations in Ha Long Bay

No	Survey locations	Longitude (degrees)	Latitude (degrees)
1	Dau Go cave	107° 1' 0.426"	20° 54' 47.9592"
2	Thien Cung cave	107° 1' 8.3244"	20° 54' 42.4332"
3	Ga Choi Island	107° 1' 32.8404"	20° 53' 29.7168"
4	Luon cave	107° 5' 40.812"	20° 51' 15.5016"
5	Bo Nau cave	107° 5' 13.1676"	20° 51' 4.4424"
6	Sung Sot cave	107° 5' 29.5836"	20° 50' 44.682"
7	Ho Dong Tien cave	107° 6' 16.3512"	20° 50' 36.0096"
8	Me Cung cave	107° 5' 5.0568"	20° 50' 7.602"
9	Trinh Nu cave	107° 6' 30.5676"	20° 50' 4.416"
10	Cap La cave	107° 13' 29.9244"	20° 51' 57.87"
11	Thien Nga Island	107° 17' 14.3952"	20° 54' 19.5876"

3. Methods and data

3.1. Methods

- Field survey method: Record information on geology, topography, geomorphology, structural geology; measure the orientation of studied objects;

- Method of evaluating Karst according to the following criteria:

+ Scientific value: This criterion considers the geological and tectonic history of the research area, lithological composition, fossils, geological age, geology-geomorphology, dissolution processes, erosion of rainwater, and sea waves.

+ Aesthetic value: This criterion considers the beauty of the natural landscape, the uniqueness of the terrain, and the diversity of geology;

+ Unique, distinctive, and majestic value: This criterion considers the uniqueness of the karst in terms of its prominence, typicality, and national, regional, or international prominence.

+ Cultural value: This criterion considers historical, spiritual, mental, and legendary values.

4. Results and discussions

4.1. Results

- Landscape value

The limestone islands in Ha Long Bay have a blocky, thick, and fairly uniform layered structure, formed during the Carboniferous and Permian periods. Within these rock formations are many beautiful and notable caves, such as Dau Go, Thien Cung, Me Cung, Sung Sot, Bo Nau, Trinh Nu, and Ho Dong Tien caves. Each cave possesses its own unique and enchanting beauty, attracting tourists every time they visit the Bay.

Dau Go cave is located on Dau Go island, at coordinates $107^{\circ}1'19.956''\text{E}$, $20^{\circ}54'34.47''\text{N}$. The cave's dome is about 25 meters high, with hundreds of giant stalactites hanging down like a surreal waterfall. The cave is divided into three main chambers (Fig. 2a).

The outer chamber is arched and illuminated by natural light. The ceiling of the cave resembles a giant oil painting, depicting a wild natural landscape with

colorful stalactites and stalagmites forming unusual shapes, such as a herd of elephants searching for food, startled spotted deer, and a dozing lion. At the bottom of the cave, there is a turtle swimming in the middle of a vast lake. Standing beneath the cave ceiling, one feels as if they are inside an ancient castle, surrounded by massive and majestic architecture.

In the second chamber of the cave, the dim light makes the rock formations shimmer with mystery. Clusters of stone flowers appear and disappear, their shapes both familiar and strange, evoking a sense of both fear and curiosity (Fig. 2b).

In the third chamber, the cave suddenly opens up to reveal a fairy well filled with crystal-clear fresh water. The dim light inside makes visitors feel as if they are lost in an ancient castle. The cave walls depict a chaotic battle scene, with elephants and horses charging, people and animals jostling, swords and spears bristling- everything seems to surge forward and then suddenly turn to stone.



(a)



(b)

Figure 2: a) Dau Go cave; b) The second chamber of Dau Go cave

Thien Cung cave is located at coordinates $107^{\circ}1'13.0512''\text{E}$, $20^{\circ}54'41.13''\text{N}$, in the northern part of Dau Go island. It is one of the most beautiful caves in Ha Long Bay, with an area of up to $10,000\text{ m}^2$ (Fig. 3a).



(a)



(b)

Figure 3: a) Thien Cung cave; b) The first chamber of Thien Cung cave

Thien Cung cave consists of three chambers. The first chamber stands out with a giant painting on the cliff wall (Fig. 3b). On the Eastern side, vivid images of fairies and animals are depicted with soft and delicate lines. On the Northern side, there are images of fairies gracefully singing and dancing. From the vaulted ceiling, stalactites hang down like sparkling crystal chandeliers.

The second chamber is the central area of the cave, featuring a stunningly magnificent landscape (Fig. 4a). The stone

pillars are massive, varied in shape, and intricately carved from base to top. From the ceiling, the stalactite formations hang down like a magnificent curtain. Along the walls are vivid images of flowers, birds, and fairies dancing and singing.

The third chamber is like a paradise in the heart of the earth, with a hazy atmosphere that reflects the beauty of the stone formations (Fig. 4b). In this chamber, there are clear lakes with murmuring water that flows all year round.



(a)



(b)

Figure 4: a) The second chamber of Thien Cung cave; b) The third chamber of Thien Cung cave

The path to Thien Cung cave is built with stone steps, shaded by cool green forest trees. The cave entrance is located about 25 meters above sea level. The cave itself is approximately 120 meters long and over 20 meters high.

Sung Sot cave is located on Bo Hon island, in the center of Ha Long Bay, at coordinates 107°5'46.7124"E, 20°50'36.4164"N (Fig. 5a). It is one of the largest and most magnificent caves in the area. Sung Sot cave is divided into two main chambers.

The first chamber is as large as a theater, with the ceiling covered in a smooth layer resembling a “velvet carpet”. Inside the cave are countless stalactites hanging like glowing chandeliers, along with stone statues resembling elephants, seals, raspberries, flowers, and leaves seeming to quiver, as if suspended between reality and dreams.

The second chamber is immense, capable of accommodating thousands of people. As visitors go deeper, the scenery becomes even more surreal, with formations that resemble ancient banyan trees with lush foliage, sea bears, dinosaurs, and more. At the highest point of the cave, a “royal garden” opens up,

featuring a clear lake and beautiful landscape. A variety of plants and many species of birds thrive here, creating a picturesque natural space.

MeCungcaveislocatedatcoordinates $107^{\circ}5'22.218''\text{E}$, $20^{\circ}49'57.5004''\text{N}$, at an altitude of 25 meters on Lom Bo island (Fig. 5b). This cave has a complex structure with multiple levels, numerous chambers, and dividing cliffs, forming a natural “maze”. Me Cung cave is also notable for its large stone pillars and clusters of stalactites hanging from the ceiling, displaying diverse shapes such as statues, patterns, stone lions, stone bears playing with each other, and stone curtains flowing down the cave walls.



(a)



(b)

Figure 5: a) Sung Sot cave; b) Me Cung cave

Me Cung cave has been identified by archaeologists as one of the sites belonging to the Pre-Ha Long culture from the early Neolithic period, dating back 7,000 to 10,000 years ago.

Base caves are caves with large floors, usually located at relatively low elevations above sea level. They are mainly formed by chemical and mechanical erosion caused by water and sea waves during the transgressive phases of the Neogene and Quaternary periods, especially the final transgressive phase (Flandrian).

The stalactite system in the caves formed after the sea receded, causing the caves to emerge above the water surface. Typical beautiful base caves include Bo Nau, Ho Dong Tien, and Trinh Nu caves.

Bo Nau cave, located at coordinates $107^{\circ}5'23.1108''\text{E}$, $20^{\circ}50'53.6856''\text{N}$, is one of the most beautiful and ancient caves in Ha Long Bay, covering an area of about 200 m², with a wide and flat cave floor (Fig. 6a). The cave entrance is dome-shaped like an upside-down clamshell, creating a private space that feels like the

ceiling of a theater. There are cracks in the cave ceiling that allow light to penetrate inside. The bottom of the cave is narrow, with an island in front, so the light inside the cave is always gentle and never glaring. Above the cave entrance are three stone slabs shaped like three fairies with their heads together, positioned as two people playing chess and one acting as the referee.

Ho Dong Tien cave, located at coordinates $107^{\circ}6'18.108''\text{E}$, $20^{\circ}50'39.12''\text{N}$ on Bo Hon Island, is a

typical cave with a floor situated low relative to sea level and the entrance is often flooded (Fig. 6b). Unlike other caves in Ha Long Bay, the stalactites inside this cave have vivid shapes, as if delicately and elaborately carved by the hands of nature, with magnificent, majestic lines resembling a palace. The cave floor is quite firmly consolidated with CaCO_3 . However, the lower part of the floor has been eroded by underground flows that have been present in the cave for thousands of years.



(a)



(b)

Figure 6: a) Bo Nau cave; b) Landscape of Ho Dong Tien cave

Trinh Nu cave is estimated to date from the Late Pleistocene to the Middle Holocene [14], and is located on Bo Hon island at coordinates $107^{\circ}6'47.7252''\text{E}$, $20^{\circ}49'56.2548''\text{N}$ (Fig. 7a). The cave consists of 3 compartments, connected through narrow doors. The outermost compartment is spacious, with a fairly flat bottom. The middle compartment has countless stalactites forming strange shapes. The innermost compartment is rectangular, tall, and wide, with sparkling stalactites on the cliff, forming a vivid relief.

Frog-jaw caves are formed by the erosion caused by seawater and modern tidal waves. In general, the limestone islands in Ha Long Bay have eroded,

concave bases that form frog-jaw caves. Some frog-jaw caves extend deep into the islands, even penetrating the limestone blocks to the opposite side, thus forming caves.

These caves often have fairly flat ceilings, with heights equal to or higher than the high tide level, while the cave floors are often submerged below sea level. The caves in the Ba Ham Lake system are typical examples of this type of cave. Smaller caves of this kind are quite common throughout Ha Long Bay.

The cave system in Ba Ham lake, located on Dau Be island at coordinates $107^{\circ}5'59.406''\text{E}$, $20^{\circ}51'7.0056''\text{N}$ (Fig. 7b), was formed by the chemical corrosion

of seawater combined with the abrasive effects of tidal currents and waves, and is dated to the middle Holocene (Waltham, 1998). Ba Ham lake consists of three nearly circular saltwater lakes, formed from three karst funnels with submerged bottoms beneath the sea. These lakes are connected through narrow, winding

caves. When the tide is low, visitors can enter the caves by bamboo boat or kayak. Inside, you will see a forest of multi-colored, sparkling stalactites hanging from the cave ceiling. At a bend, the cave suddenly darkens, then suddenly a green light shines down, signaling the arrival at the next lake.



(a)



(b)

Figure 7: a) Trinh Nu cave; b) Luon cave

- Geological and geomorphological values

The outstanding values of the geological heritage of Ha Long Bay are reflected in its diversity and uniqueness compared to other areas, especially in the richness of geological events and fossil complexes of animals and plants. Ha Long Bay and its surrounding areas have a strongly differentiated terrain, most of which is submerged underwater. However, even the parts above water demonstrate that Ha Long Bay has a long history of geological development, from the Ordovician period (nearly 500 million years ago) to the present. Tectonic imprints are clearly expressed through the mountain-building activities of the Caledonian, Indosinian, and Himalayan orogenies, which can be recognized through simple or complex faults and folds on limestone islands.

The geological and geomorphological values of Ha Long Bay are typical examples of karst landforms on mature limestone islands, formed in hot and humid tropical conditions and partially submerged under the sea. These limestone islands have been accumulating for about 100 million years (from the Carboniferous to the end of the Permian, about 355 to 255 million years ago), during a long period of calm, with a shallow, warm, and gradually sinking sea.

Currently, the limestone islands in Ha Long Bay are 100 to 200 meters high and mark ancient leveled surfaces formed in the early Neogene period. This surface dissection process occurred mainly in the late Neogene and early Quaternary periods, related to changes in ocean water levels during successive glacial and interglacial periods. During the glacial periods, the sea level receded,

the climate became dry, accelerating the formation of cliffs and creating the tower-shaped karst formations that are very common in Ha Long Bay. Conversely, during the interglacial periods, when the sea level rose, the climate was humid and rainy, promoting the formation of new sea ridges, large-scale caves, karst funnels, and underground streams. The seabed of Ha Long Bay still preserves relatively young sedimentary layers (Pleistocene and Holocene), with stepped plain surfaces, semi-submerged sea ridges, and ancient river valley systems. These valleys appear as long depressions, with an average depth of over 15 meters, and in

some places deeper than 20 meters.

4.2. Discussions

- Current status of the rocky islands

The rocky islands in Ha Long Bay have many magical shapes that change depending on the viewing angle. Highlighting this beauty are the sea ridges-traces of chemical and mechanical erosion by seawater at the base of the limestone islands. At low tide, thousands of islands expose their “waist” sections, barely above the water level. Some islands resemble large, slightly tilted towers with tapered bases, as if they could collapse at any moment (Fig. 8).



Figure 8: (a) Foot of a stone tower, (b) Ga Choi island is gnawed by ocean waves, and chemical corrosion (Coordinate 107° 1' 48.0108", 20° 53' 21.0156")



Figure 9: Current status of landslides in Cap La cave in Ha Long Bay (107° 13' 43.0824", 20° 51' 54.5868")

The same type of erosion in the tidal zone created Luon Cave and some other caves in Ha Long Bay. When the tide recedes, small boats can pass through the cave to the water and sky on the other side of the rocky island.

In addition, due to the impact of other external factors, some caves and rocky islands have collapsed (Figures 9 and 10).



Figure 10: Current status of the broken and smashed stalactite system in Tien Ong cave, Ha Long Bay ($107^{\circ} 7' 41.2788''$, $20^{\circ} 48' 51.1236''$)

In 2016, the impact of failure led to the disappearance of the head of the Thien Nga island, affecting the sustainable development of the heritage area (Fig. 11).

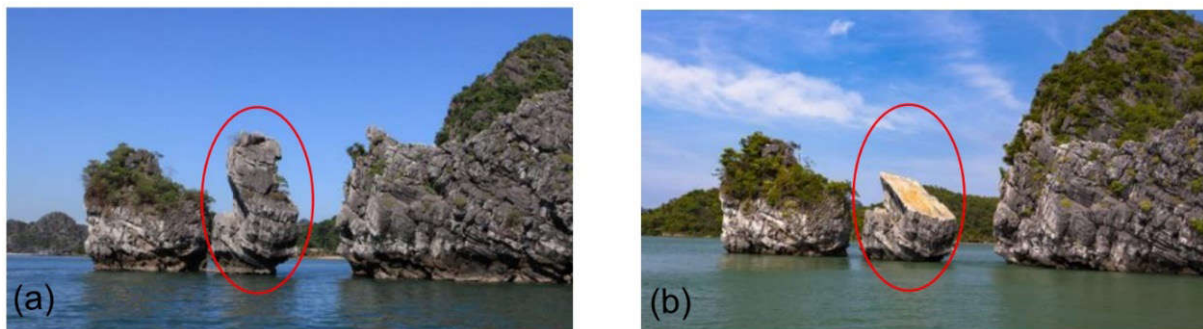


Figure 11: The head of Thien Nga island (HL-06) was cut due to the plane's failure (a and b)

- Discussions

The studies on Ha Long Bay have been carried out for many years of the last century and focused mainly on the landscape, geology, and geomorphology [3, 4, 5, 8, 9, 10, 12,

13, 14]. However, landslide studies in this area have only been conducted recently. Typically, a provincial-level scientific and technological research project with the topic: “Research on geological processes, modern geodynamics for observation of changes in caves and islands in Ha Long Bay” was performed by Van (2012). The results of this study have been analyzed and assess the possible risk of rock slides on limestone islands to support planning, conservation, and hazard mitigation. Recently, Phi T.T et al., (2017) used

Hoek and Bray (2004)’s application to identify the failure types that can occur on limestone blocks of Carbon-Pecmi age in the northern area of Ha Long Bay, and it was indicated that this place can mainly occur plane failure [1, 4].

In 2019, Thanh used Hoek and Bray’s (2004) application to identify the failure types on Bai Tho, Dinh Huong, Ga Choi, But, and Thien Nga islands, indicate the risk of sliding types, and simulate 3D sliding mass on these islands.

- Potential failure on Ga Choi island

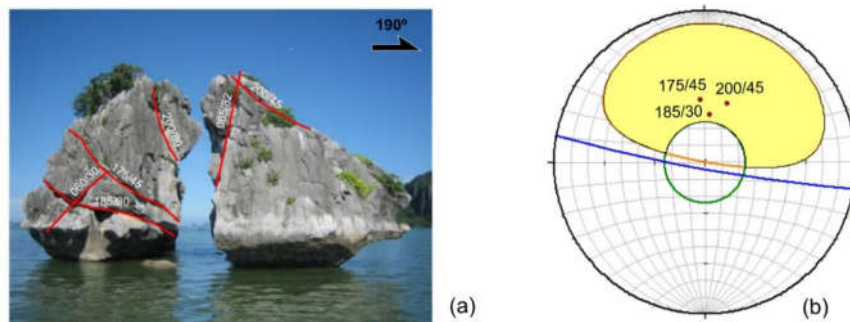


Figure 12: (a) Photo of fractures on Ga Choi island, (b) Plane failure potential can occur on the fracture orientations: 175°/45°, 185°/30°, and 200°/45° and slope orientation 190°/85 - 90° [3]

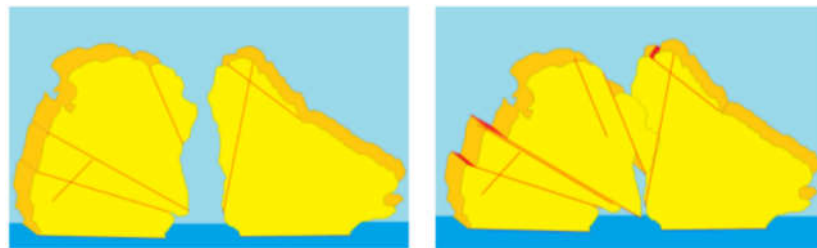


Figure 13: 3D model of limestone block and potential failure on Ga Choi island [3]

Potential failure on Thien Nga island

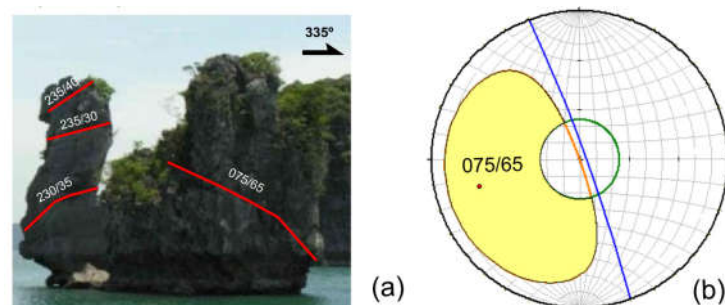


Figure 14: (a) Photo of fractures on Thien Nga island, (b) Plane failure can occur on the fracture orientation 075°/70° and slope orientation 230°/85 - 90° [3]

The model of plane failure

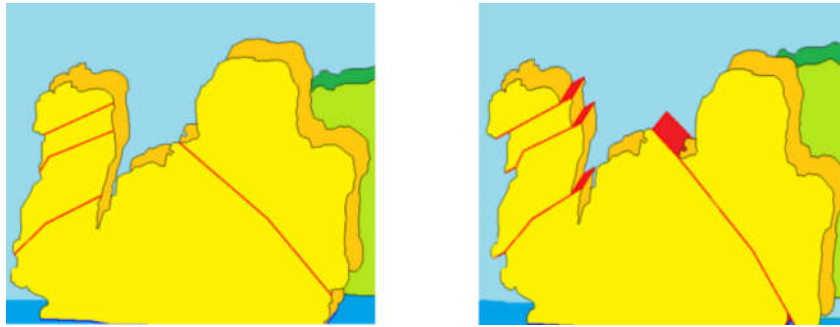


Figure 15: 3D model of limestone block and potential failure on Thien Nga island [3]

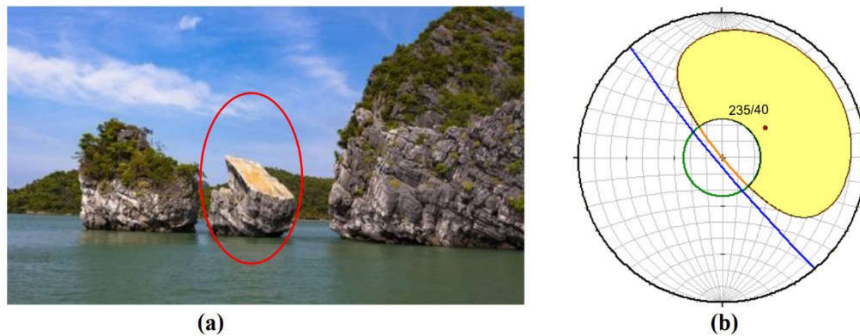


Figure 16: A head of Thien Nga island is cut by the plane failure of fracture orientation 235°/40° (a, b) (107° 17' 14.39", 20° 54' 19.59") [3]

Thanh's (2019) research clearly shows the potential for landslides on limestone islands in Ha Long Bay and proposes solutions. In addition, due to the impact of sea waves and chemical erosion at the bases of limestone mountains, some limestone islands in Ha Long Bay may collapse and are at risk of disappearing.

The analytical results presented in this article are important, supporting heritage conservation by providing solutions to preserve Ha Long Bay's world heritage, which is a gift from nature.

5. Conclusion

The impacts of geological tectonic activity, ocean waves, seawater dissolution, and other exogenous factors over various periods have shaped unique landforms on the coastal limestone mountains, islands, and prominent karst caves - both above and below sea level in

the Ha Long Bay area. These landforms include ancient plains, funnels, karst valleys, clusters of conical hills, high stone towers, vertical cliffs, and isolated formations, all contributing to the majestic landscape of Ha Long Bay. The analytical results show that some islands and caves in the bay have experienced serious landslides, collapses, and erosion caused by ocean waves and the chemical corrosion of seawater, affecting the beauty of this world natural heritage site. These findings provide valuable information for managers to support the protection and conservation of Ha Long Bay's natural heritage.

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