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Karst and Caves of Ha Long Bay

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Introduction

Ha Long Bay is distinguished by the hundreds of small limestone islands that rise steeply or vertically from its shallow waters. Its dramatic and beautiful landscape is deservedly famous as one of the world's outstanding natural sights, but it is also a UNESCO World Heritage Site of international geomorphological significance (Fig. 1). The bay lies on the northeastern coast of Vietnam, immediately east of the Red River delta. It is bounded on the north by the mainland hills either side of Ha Long City (also known as Hong Gai), to the south by the open waters of the Gulf of Tonkin, to the west by Cat Ba Island, and to the east by islands of sandstone (Fig. 2). Ha Long Bay has an area of about 1500 km^2, and contains nearly 2000 limestone islands.

The caves described here were all visited during an assessment of the bay's geomorphology with respect to its position as a World Heritage Site. Records of other caves in Ha Long Bay are sparse. A British team led by Howard Limbert mapped the Hang Hanh stream cave in the mainland limestone along the north shore of the bay; and a French team led by Marc Faverjon explored caves in the islands east of the bay, and also a few in Ha Long Bay itself.

Locality names are here translated into English, except for the cave names which are left in Vietnamese. The key terms are: *dao* = large island; *hon* = small island or rocky tower; *hang* = tunnel or passage cave; *dong* = chamber cave.

Fig. 1. The view out from Hong Gai harbour, with the limestone islands extending out into Ha Long Bay.

Fig. 2. Location of Ha Long Bay in northern Vietnam.

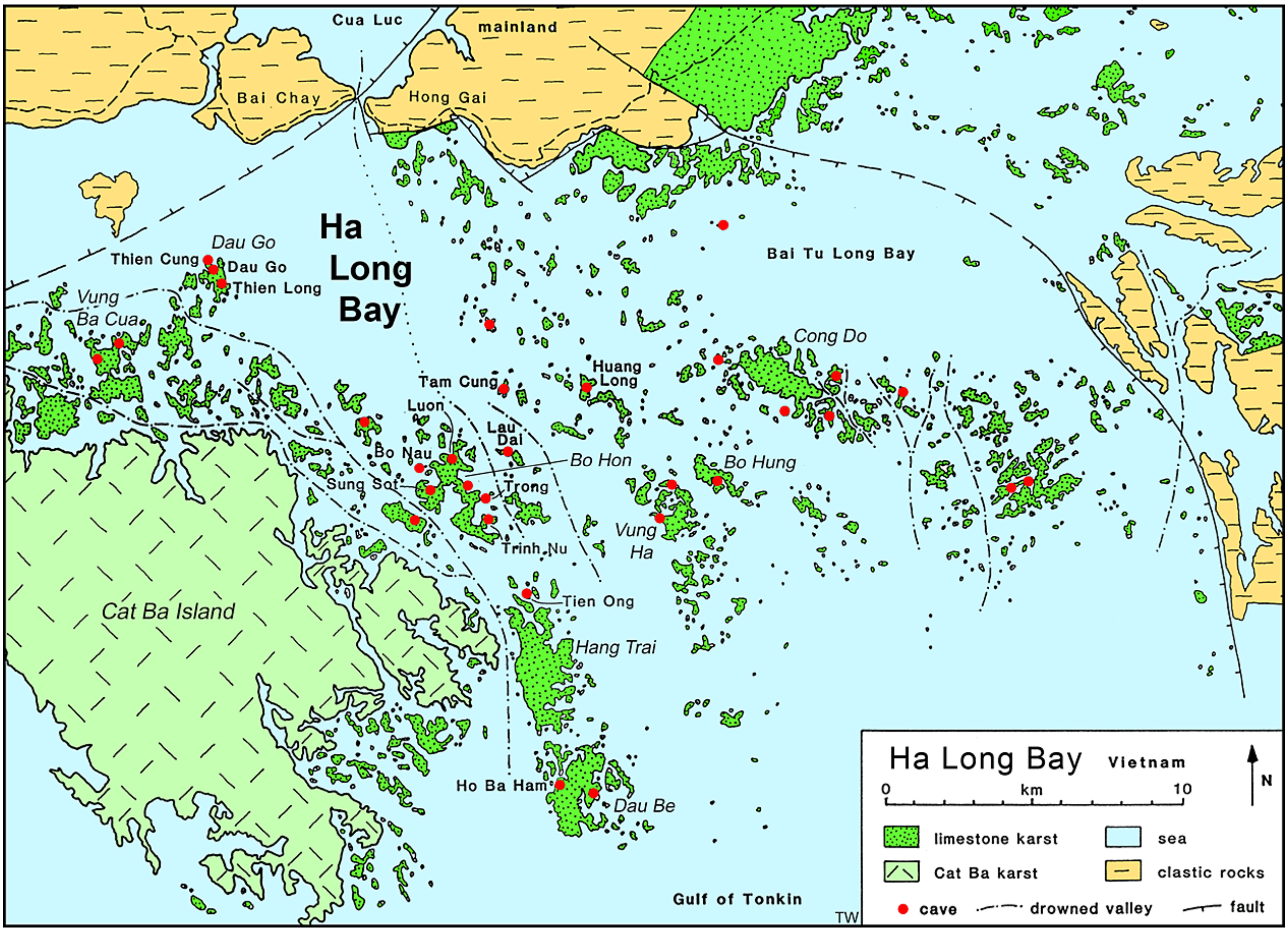

Fig. 3. A simplified map of Ha Long Bay, showing the larger islands and the outline geology, and naming some of the larger caves.

The islands of Ha Long Bay are all cut in a folded sequence of Carboniferous and Permian limestones that reaches to more than 1000 m thick. These pale grey limestones are strong, fine-grained materials, ideal for the development of karst. Beds vary from 500 mm to 5 m thick, and very thin shale partings occur on many of the bedding planes; chert is a minor feature, and there is patchy dolomitisation at a few localities. Across most of the bay, the limestones dip to the west, but the structure is complicated by north-south faults. Cat Ba Island is distinguished by limestone hills with slope angles lower than those of the bay islands; it appears to be formed largely in a more thinly bedded series of Carboniferous limestones than those that underlie the bay. Small areas of karst on islands east of the bay are formed on Devonian limestones that occur within the sandstone sequence.

The mainland north of Ha Long Bay is formed largely of Triassic coal measures. These are complexly folded and contain anthracite seams up to 50 m thick that are mined in large open pits. The boundary of the coal measures with the limestone is almost along the coast, and this is largely faulted. The geological structure of the Ha Long Bay limestones appears to be very complex, and some of the drowned valleys between islands are probably fault-guided. Bedding is close to horizontal in the eastern part of the bay, but elsewhere dips at any angle, and small overfolds occur in the western part of the bay. The structure has little influence on the karst geomorphology, as slope profiles on the islands are largely independent of the limestone dips.

The karst of Ha Long Bay

The strong pure limestones of Ha Long Bay have been eroded into a mature landscape of fengcong and fenglin karst. This evolved by normal subaerial erosion of the limestone, but was then invaded and slightly modified by the sea at a late stage.

The hundreds of rocky islands which form the most beautiful and famous landscapes in the bay are individual towers in a classic fenglin landscape where the intervening plains have been submerged by the sea (Fig. 3). Most towers reach heights of 50 to 100 m, with height/width ratios up to about 6. Many towers have vertical walls on all or most sides; these continue to evolve by rockfalls and large slab failures. In 1997, a large slab peeled off a small island north of Cat Ba, to create a new vertical face; the main failure surface was on vertical fractures, part of which had been opened to form a cave subsequently partly refilled with large stalactites, and the fallen block of around 500 m^3 now lies in the sea where it is being eroded by dissolution and wave action.

Many of the towers have very old cave remnants preserved within them, and many have foot caves that are relicts of their undercutting at various levels (Fig. 4). Clusters of limestone hills form the larger islands within Ha Long Bay, and represent fine examples of fengcong karst. Summits are generally at around 100 m above sea level, and the highest peaks reach heights of over 200 m. Their profiles are mostly very steep cones; except around their marine margins, vertical cliffs are only minor components, as they have not been subject to lateral undercutting where their internal dolines do not reach down to base level. These conical hills also contain remnants of old cave passages. Some of the fengcong hills have individual slopes or sides which are formed on steep bedding planes within the limestone; beyond these sites the geological structure has very little influence on the limestone hill profiles.

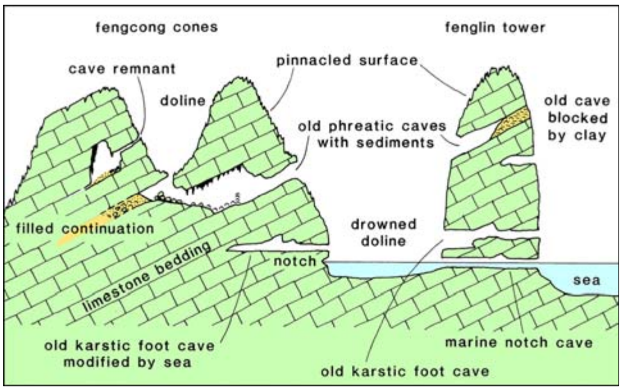

Fig. 4. Diagrammatic profile showing the main types of cave in the Ha Long Bay karst.

Fig. 5. The Luon hong, with the sea-level cave entrance through the limestone tower towards the right.

Fig. 6. The doline lake in the interior of Cong Do island.

A distinctive feature of Ha Long Bay is the abundance of lakes which lie inside the limestone islands. Dau Be Island, at the mouth of the bay, has six enclosed lakes, including those of Ho Ba Ham. All these island lakes occupy drowned dolines within the fengcong karst, and are known as hongs in other parts of southeast Asia (Fig. 11). Their depth profiles have not yet been surveyed; most appear to be deep, but some have shallow areas over planation surfaces just below their water level, and most have marine solution notches around their walls. They are tidal, as sea water moves freely through the limestone, at some sites through sea-level caves which are traversable by boat, but at other sites through inaccessible fissure networks. One freshwater lake is known on the eastern part of Cong Do Island (Fig. 6); it probably survives on a doline floor of clastic sediment, but details of its geomorphology are unknown.

Many of the areas of shallow sea between the limestone islands appear to be karst plains which have been submerged by the sea; most of the bay is less than 10 m deep. Clastic sediments cover much of the sea floor; most are probably of marine origin, though remnants of subaerial sediments from original karst plains may survive in the buried sequences. The drowned plains across the inner parts of the bay are sited where drainage from the Red River and the mainland flowed onto the limestone. The patches of fengcong karst which now form the larger islands probably originated as areas of slightly higher ground or fewer dolines in the initial surface from which the modern karst evolved.

All the limestone surfaces on the Ha Long Bay islands are fretted by dissolution. The pinnacles, ridges and blades of remnant rock all have surfaces of razor-sharp rillenkarren, creating an inhospitable terrain which is very difficult to cross. Jagged open fissures continue to depth and there is no continuous soil cover, and no sub-soil rundkarren. Largely organic soil accumulates in some limestone fissures, where it provides a rooting medium for the ubiquitous scrub vegetation. All limestone surfaces are black due to the blue-green algae that live in the surface crust of the rock and aid its pitting by biogenic dissolution.

Marine erosion of the limestone

Marine invasion of the Ha Long Bay karst has added an extra element of lateral undercutting of the limestone islands. The most conspicuous feature is the main marine notch cut into most of the rocky coastlines. Its deepest zone is generally nearly 3 m high, occupying the levels between normal high and low tides. It is a complex feature, commonly with a shoulder at its mid-height and a lesser undercut extending another metre higher; the latter may represent erosion by high wave action and at spring high tides. Further notches at higher levels were cut at times of higher sea level and are no longer active. Features below low tide level have not been observed, but there is no evidence of any wide wave-cut platforms.

Across the bay, there is no variation in the size of the notches which relates to exposure to the larger waves that derive from the open sea. This indicates that the notches have been cut largely by dissolution of the limestone. Sea water is normally saturated with respect to calcium carbonate, and limestone dissolution is therefore dependant on aggressive micro-environments created by algae in the surface layers of the limestone. The dark crusts with blue-green algae, that are ubiquitous on the subaerial limestone outcrops, do extend down the cliffs into the tidal range; marine algal forms are probably equally widespread, but have not yet been documented. Limestone dissolution is also enhanced at sea level by the mixing of sea water and fresh water within the fissure systems of the islands. Notches are a feature of limestone coastal cliffs worldwide, but those of Ha Long Bay are exceptionally well developed, and at many sites extend back into arches and caves (see below).

Undercutting in the marine notches is presently the major process in the erosion and retreat of the limestone cliff faces. Marine erosion has not only added the notches to the profiles of the limestone islands, but it also maintains the steep faces of the fenglin karst towers, and thereby perpetuates the spectacular nature of the karst landscape (Fig. 7).

Fig. 7. A small rocky island in Ha Long Bay; the remains of a fenglin tower, it is undercut by a marine notch, and a chunk of cliff has recently fallen off so that it now rests on the submerged rock platform.

Many of the bay islands have narrow peninsulas formed by high limestone ridges that are bounded by cliffs; these separate and overlook bays which are much wider than the intervening land fragments, as at the northern ends of Dau Be Island. Ridges that link chains of peaks are created in fengcong karst where there are favourable patterns of large dolines. Under normal weathering conditions, these degrade into lower cols, eventually to leave isolated karst peaks. The very narrow limestone aretes of Ha Long Bay are not typical of subaerial fengcong karst. They are a consequence of more rapid lateral expansion of the intervening depressions, and appear to be a feature of marine erosion. Their presence indicates a significant component of marine action in the evolution of the Ha Long Bay geomorphology.

The caves in the islands

Within Ha Long Bay, the main accessible caves are the older passages that survive from the times when the karst was evolving through its various stages of fengcong and fenglin. There are three types of caves in the limestone islands - remnants of old phreatic caves, old karstic foot caves, and marine notch caves.

Remnants of old phreatic caves

Many of the bay islands contain fragments of large or small cave passages that are partly choked with debris, mud or stalagmite. These are remnants of very old cave systems that were mostly phreatic. They occur at all levels in the limestone islands, and are distinguished from the other cave types by their sloping passages and considerable vertical range. Active phreatic caves must exist within the deeper limestone, but none has yet been found.

Hang Sung Sot is a large fragment of very old cave passage (Fig. 8), the largest of three caves in Bo Hon Island. From the entrance chambers that are truncated at a balcony high in the cliffs, a passage more than 10 m high and wide (Fig. 9) descends gently to the south and then rises to a massive choke of boulders and stalagmites; a small exit above this emerges in a chaos of fretted limestone under a canopy of vegetation. The main cave has various levels of flowstone and false floors, and ways may exist through the boulder floors into lower passages. There is some active stalagmite growth, and one dry basin is floored with cave pearls. Daylight reaches far into the cave, but the northern aspect prevents the intrusion of direct sunlight, and there are no phytokarren.

Dong Tam Cung is a large phreatic fissure cave developed in the bedding of the dipping limestone. Massive flowstone and stalactite development has divided the single fissure cave into three chambers, obliquely above each other, over a height range of about 20 m. There appears to have been only a single phase of cave enlargement, followed by draining and calcite deposition that continues today.

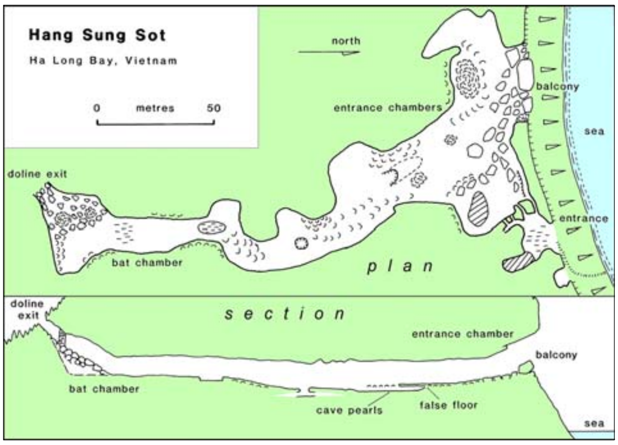

Fig. 8. Plan and section of Sung Sot Cave in Bo Hon Island.

Fig. 9. Looking into Hang Sung Sot from its balcony entrance, with the main passage extending beyond the person in the white shirt beside stalagmite on right.

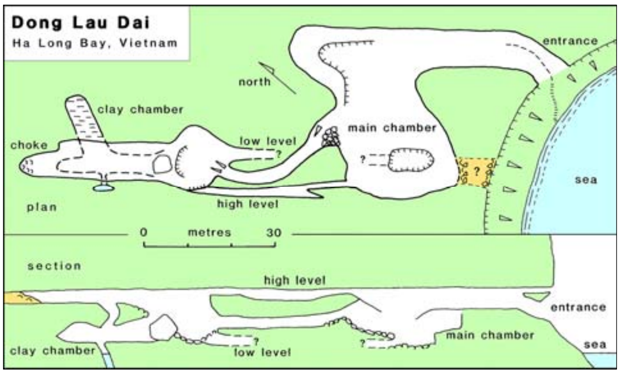

Fig. 10. Plan and section of Lau Dai Cave in Bo Hon Island.

Dong Lau Dai is a cave with a complex of over 300 m of passages (Fig. 10). The main chamber has an entrance passage open to the cliff, while its southwestern end appears to be a choke of boulders, mud and stalagmite which is also truncated by the cliff. The passages to the north are on three levels, developed on separate bedding planes and each aligned along the strike where the dip is about 10° southwest. There are thick deposits of mud and some large stalagmites.

Dong Thien Cung and Hang Dau Go are two remnants of the same old cave system that both survive in the northern part of Dau Go Island at between 20 and 50 m above sea level. Thien Cung has one large chamber more than 100 m long, blocked at its ends and almost subdivided into smaller chambers by massive walls of stalactites and stalagmites. Flowstone, false floors and gour deposits cover part of its floor; the whole cave is very beautiful, and has been developed as a tourist site by building a looping path between its two fissure entrances. The roof is a spectacular series of phreatic domes, and there are younger muddy passages beneath the chamber floor. Hang Dau Go is a single large tunnel descending to a massive choke. A high-level side chamber contains stratified sediments that have been excavated in the distant past, probably for nitrates.

Dong Huang Long is a short cave entered at beach level. A chamber over 12 m high has remnants of calcite false floors high on its walls, and a soaring shaft breaks through its roof. Two passages end in chokes, and a small passage at the top of a steep gour ramp extends to the lip of a shaft.

Truncated fragments of many other very old caves are exposed in the island cliffs. They occur at various altitudes up to 50 m above sea level. Some are partly filled with calcite and clastic sediments, and flowstone false floors are common; others remain as open tunnels.

The sea cliff on the south side of Cong Thau Trong Island exposes a vertical section through a breccia pipe. This consists of a column of limestone blocks which have fallen progressively from the roof of a cave, so that the void has migrated upwards, from the original cave below sea level.

Old foot caves

Foot caves are a ubiquitous feature of karst landscapes that have reached a stage of widespread lateral undercutting at base level. They include small notches at the foot of cliffs and also more extensive horizontal maze caves. None is active in Ha Long Bay, because their sites have been invaded by the sea to become the marine caves.

There are fewer foot caves than would be expected in such a mature karst, and they are nearly all in the larger islands that have a cover of soil and vegetation; the smaller islands that have little soil on their rocky tops have neither foot caves nor karstic notches. This suggests that mixing corrosion is critical to the development of foot caves, and only the larger islands gather enough rainfall to provide corrosive fresh water that mixes with the salt water. On the smaller tower islands, marine notches and cliff retreat progress more rapidly than do solutional foot caves.

Hang Trinh Nu is one of the larger foot caves in the bay; it extends beneath a conical hill and right through a peninsula on Bo Hon Island, between the main entrance and the bay-overlook exit that are about 80 m apart (Fig. 11). The main passages are all at the one level, with their ceilings at about 12 m above sea level. Floor heights vary, due to accumulation of stalagmite, and two large shafts rise into darkness. Notches in the walls at various levels are partly filled by stratified calcite and clay, as evidence of multiple stages in the cave's development.

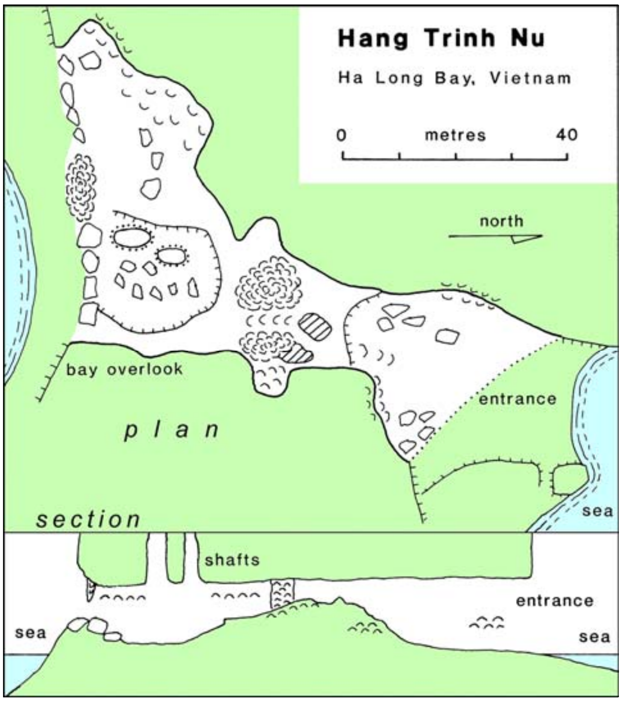

Fig. 11. Plan and section of Trinh Nu Cave in Bo Hon Island.

An unnamed foot cave extends for 40 m right through a small island east of Cong Do (Fig. 12). The main tunnel is at its widest about 6 m above sea level; at the same level it extends into smaller side chambers and a passage which rises gently along a bedding plane. Both the latter and a section of large tube may represent earlier phreatic relics. A foot cave on an island south of Cong Do has a single, horizontal passage with an elliptical profile 5 m high and over 15 m wide. It extends 100 m to a choke of flowstone and gour dams, and may continue further. Roof domes rising up to 4 m are relics of its phreatic enlargement. Hang Bo Nau is a horizontal cave about 70 m long, containing old stalagmite deposits; it is notable for the way that its passage clearly cuts across the 25° dip of the limestone bedding, and also for its exit view of the island karst (Fig. 13).

Fig. 12. The old foot cave that reaches through the small island of Xac Kha, east of Cong Do.

Fig. 13. The fengcong karst of Bo Hon Island silhouetted by the entrance of Bo Nau cave.

Vung Ba Cua Island has a remnant of large old phreatic cave that completely breaches the narrow limestone ridge linking to its northeastern peninsula. Almost below it, a foot cave extends in 50 m at just above sea level; its roof is a calcite false floor, and there appears to be another foot cave passage at a level about 8 m higher. Thick clay in the lower passage has been worked for pottery.

Remnants of marine oyster beds survive cemented to the walls of some of the old foot caves. They date from times when the caves were temporarily invaded by high sea levels. A concentration of the oyster beds at around 6 m above sea level may correlate with terraces at that altitude around the Red River delta, which are ascribed to mid-Holocene times.

Marine notch caves

Since their invasion by the sea, the karstic hills and towers of Ha Long Bay have been modified by marine erosion; the process continues today. Dissolution of the limestone creates cliff notches that may extend into caves; many of these extend right through the limestone hills, into drowned dolines which are now tidal lakes or adjacent bays. A distinguishing feature of these marine caves is a smooth, horizontal ceiling that cuts through the limestone. Many also have phreatic roof domes recessed into their otherwise flat ceilings, and it is likely that part of their development was as subaerial foot caves, with components inherited from even older phreatic caves.

One of the most distinctive features of Ha Long Bay is the Ho Ba Ham group of hidden lakes and their connecting caves in Dau Be Island (Fig. 14). From the island's perimeter cliff a cave extends about 150 m to Lake #1; the passage is 10 m wide at water level, and curves so that the centre is almost dark and requires some care when passing through in a boat. At low tide there is a minimum of 1.5 m of airspace, over water that is at least 2 m deep. The second cave, through to Lake #2, is of similar cross section but only about 60 m long. A cave through to Lake #3 is smaller, and may only be traversed by a canoe; any links to Lakes #4 and #5 have not been checked. In the two larger caves, most of the ceiling profile is a perfectly flat corrosion surface. Bulbous stalactites up to 1 m in diameter hang from the cave roofs, and largely postdate the ceiling planation.

There are similar marine caves at many other sites in Ha Long Bay. Hang Luon (Fig. 15) extends 50 m through to an enclosed tidal lake. An unnamed cave extends about the same length into Lake #6 on the east side of Dau Be Island, and notch caves link adjacent bays on the west side of Vung Ha Island and on the south side of Bo Hung Island. A cave into the eastern tip of Cong Do Island carries sea water in and out of a drowned doline lake; its passage is about 4 m high and wide, and it is a very fine stream cave in clean rock, unusual only in that its flow reverses with the ebb and flow of the tide.

All these caves range in width from 8 m to 20 m. They have phreatic domes in their ceilings, and parts of them are breaking upwards in fractured limestone to create low stable arch profiles. The flat ceilings in these marine caves are above present high water levels, and many of them are draped with stalactites. They are clearly old erosion surfaces, created largely by dissolution in times past when sea levels were higher in the Pleistocene. Hang Luon has a massive stalactite hanging 2 m down from a flat roof, and the stalactite is truncated at the modern high tide level.

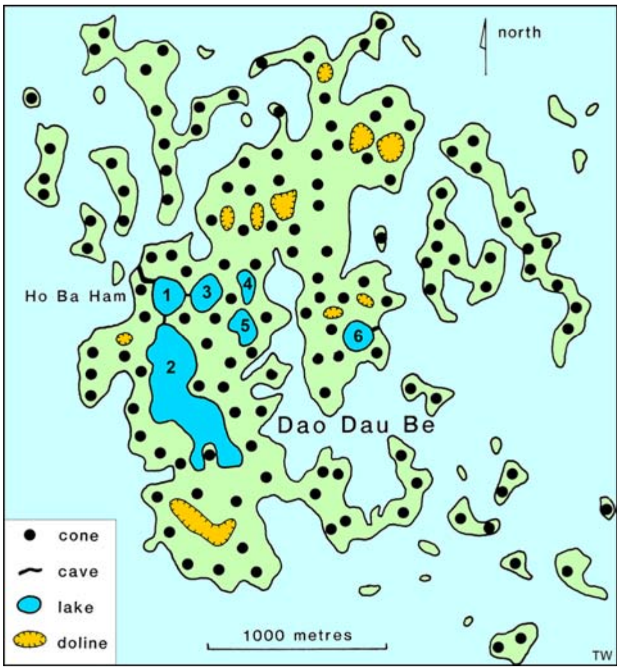

Fig. 14. Outline map of Dau Be Island showing the dolines and hong lakes that lie between the conical hills of the drowned fengcong karst.

Fig. 15. Hang Luon, a marine notch cave that extends through to a large hong lagoon.

Evolution of the landscape

Karstic evolution of the Ha Long Bay limestone area must have continued through much of Neogene time (20M to 2M years ago), as mature fengcong and fenglin landforms can only evolve through millions of years of erosion and surface lowering. In panoramic views across the bay islands, there is generally little suggestion of any concordance of summit heights that could relate to intermediate Neogene erosion levels. Remnants of old phreatic caves survive at various levels within the bay islands, but their altitudes are not easily related to their ages.

The topography of the bay's sea floor is only known from the limited available map data, but it appears that most of it has very little relief, and the great proportion lies at depths of less than 10 m. This morphology is compatable with an origin as a subaerial karst plain, which has been subsequently drowned by the sea.

The major impact on Ha Long Bay of the worldwide climatic oscillations during the Pleistocene was the periodic lowering of sea level. During cooler stages, water was locked into the icecaps of higher latitudes, and sea level temporarily declined by about 100 m. This happened many times, and between these events sea levels were close to those of the present day. When the sea level was low, the whole of Ha Long Bay was dry land. Subaerial karst processes continued on the limestone basins and plains between the cone clusters and towers. Allogenic drainage from the north fed rivers across the bay area. These excavated valleys are now drowned, but none reached contemporary sea level until it was far to the south of the modern bay site.

Limited mapping of the bay's sea floor indicates that, though these drowned valleys reach depths of 20-30 m below present sea level, they are discontinuous and do not continue to deepen to the south (downstream). They may represent segments of valleys that lay between caves carrying their rivers through intervening limestone ridges. Alternatively, the sea floor bedrock topography may be masked by extensive accumulations of clastic sediment. The main open part of Ha Long Bay has a floor of thick sediment; large ships to and from Cua Luc have to follow a channel that was excavated through this, but is now kept clear by natural scour. When sea level was low during the cold stages of the Pleistocene, karstic evolution was rejuvenated, so that dolines were deepened, while the cones and towers were degraded.

Many of the caves now at or just above sea level were used as sheters from 18 000 to 12 000 years ago, when sea levels were low during the Devensian glacial stage. The cave dwellers left behind vast banks of freshwater and terrestrial gastropod shells which testify to the remoteness of the contemporary sea; some of these shell banks have subsequently been cemented to the cave walls by calcite deposition.

Marine undercutting of the limestone islands at sea level is a conspicuous feature of Ha Long Bay. Its extent is more than could have been created solely in the Holocene; the many limestone ridges that have been reduced to narrow aretes by coastal retreat are indicative of a long period of marine erosion. Much of the marine morphology of the limestone islands dates from the warmer phases of the Pleistocene when sea levels were close to that of today. The complex marine cliff notches and the multiple levels of dissolution features in the associated notch caves further indicate that sea level erosion has been active over a long period of time, when sea levels have not been absolutely constant.

Acknowledgements

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