

## Karst and caves of Palau.

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**Abstract:** The Rock Islands of Palau, in the western Pacific Ocean, constitute a partially drowned fengcong karst with forest-covered conical hills that now form numerous islands. The karst is unusual in that many of the hills are coalesced into long sinuous ridges, which might be inherited from pre-karstic marine erosion. Known caves within the Palau karst are all short, consisting of truncated old chambers and also tidal caves through to hong lakes in flooded dolines.

**Keywords:** Palau, drowned karst, marine, fengcong, hong.

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The Republic of Palau consists of an archipelago of islands out in the Pacific Ocean, 900km east of the Philippines. It is the westernmost unit of the Caroline Islands, and is part of the Federation of Micronesia. Palau has one large island (Babeldaob), which is sparsely inhabited, a trio of bridge-linked islands (including Koror) on which reside most of the population, a few minor islands with villages, and the hundreds of uninhabited Rock Islands that are all made of limestone (Fig.1). The mini-nation thrives on tourism (it is one of the world's top dive centres), American support, and modest fishing and agriculture.

In geological terms, Palau lies on a currently inactive part of the boundary between the Pacific and Philippines plates. Its roots are an island arc of largely andesitic lavas and pyroclastic rocks, from eruptions that finally ended about 20 million years ago; these now form most of Babeldaob beneath thick soil profiles and a dense forest cover. Developed on and around this volcanic core is a huge coral environment, with wide lagoons inside massive fringing reefs. The Rock Islands comprise late Miocene (and some Pliocene) limestones, lithified into good strong rock, which were formed in past versions of this lagoon (Kellett, 1991). Following subsidence and then uplift, the once-extensive limestone has been heavily eroded to create the remnants that are now the karst islands.

### Karst of Palau

Though named the Rock Islands, and clearly all made of sound limestone, these hundreds of islands are all shrouded in thick forest. They therefore present a beautiful landscape of rounded green hills rising from a sea of blue and incredibly clear water. Perhaps the most famous panorama from Palau is of Ngerukewid (Seventy Islands), where both islands and waters are now protected by a total ban on visits within a Wildlife Preserve, so that they can only be seen from the air (Fig.2). Away from that site, the karst is a mixture of small islands that are single hills and a few much larger islands with conical and domed hills crowded round deep dolines (Fig.3).

The Rock Islands are a splendid fengcong karst that is now partially drowned by the sea (Fig.4). Though shrouded in trees, the profiles of the hills, both the individual hills that form entire islands and the clustered hills of the larger islands, appear to be dominated by low cones. The highest of these rise to just over 200m. Even where the island hills are separated by open water, most of them are crowded close enough to each other to keep within the concept of fengcong (Waltham, 2008). There is an element of immaturity within the fengcong, as many of the inter-doline ridges remain relatively high between adjacent cones, suggesting that the terrain is little advanced from its stage of doline karst. Remnants of any karst plain, as would lie within a fenglin terrain, and should now be just below sea level, are not recognisable. Most remains of karst landforms that might lie beneath the sea are lost beneath the overgrowth of Holocene coral and shell debris that floors the modern lagoons. Many sites within the lagoon have floors descending to between 30 and 50m. Between the islands, the sea floor appears to continue the profile of deep dolines that developed within a fengcong

terrain when sea level and base level was at least 30m lower than it is today. There must have been at least some evolution of the Palau karst when sea levels were declined by 100m or more during each of the Pleistocene cold stages. Beneath the Holocene sediments, Pleistocene limestones form a discontinuous, eroded platform with a top surface around 20m below current sea level (Kayanne *et al.*, 2002).



**Figure 1:** The main islands and outer reef of Palau; just off the map are the separate small atoll islands of Angaur (to the south) and Kayangel (to the north); the inset shows Palau, Yap and Guam just northwest of the eastern margin of the Philippines plate.



**Figure 2:** The beautiful karst islands of Ngerukewid that form the Seventy Islands Wildlife Preserve.

The larger islands contain saltwater lakes in the dolines within their fengcong karst. These are true hong (Price and Waltham, 2007), in that they are drowned dolines that are still tidal due to their underground hydrological connections through to the open sea. There are nearly 50 hong lakes within the Rock Islands. One of the larger of these is Jellyfish Lake, in the island of Mecherchar (Figs 2 and 5), which is more than 30m deep. This is famed for its vast numbers of stingless jellyfish, which thrive in the algae-rich water that has only modest tidal circulation and is free of marine predators. The implication is that the hong lake is linked to the sea only by a relatively tight fissure network and not by larger cave conduits that could offer access to predatory fish from outside. There are other lakes that also contain jellyfish, so might have similar hydrology. Yet another lake on Mecherchar contains turtles, so must have larger access conduits from the sea. There are also many hong lakes connected to the sea by open cave passages (see below). Additionally, another dozen or more lagoons now connect to the sea by very narrow open channels, which are again flooded dolines and are closely related to the hong.

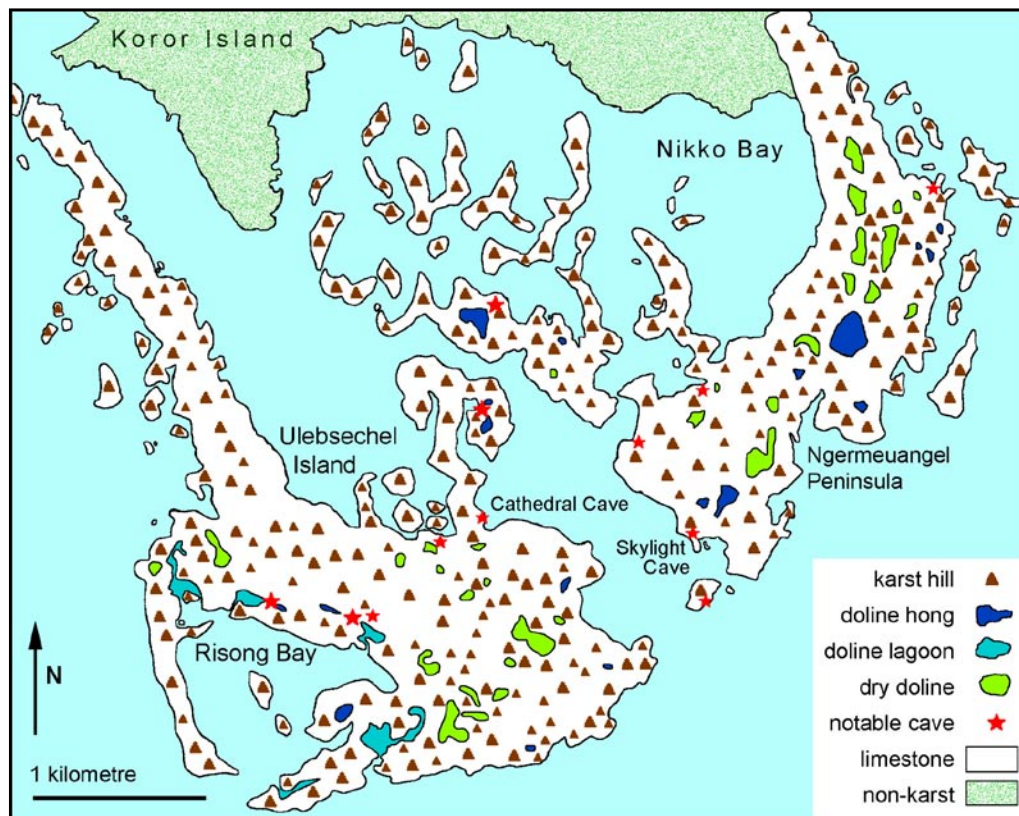
Spectacular marine notches span the tidal range round all the islands (Fig.6). Like notches in limestone elsewhere, dissolution and wave erosion contribute little to their excavation, which is largely by chitons; these are the tiny molluscs that bore into the limestone in their continual grazing of algae on and immediately beneath the rock surface (Trudgill, 1983). The notch undercutting has generated isolated small rockfalls, but there is no extensive progression towards tower development in the limestone. The Rock Islands are drowned fengcong, and they stand in clear contrast to the drowned fenglin of Ha Long Bay and other sites around the Asian coasts (Waltham, 2000).

Conspicuous within the Rock Islands karst are some very long ridges that now form long, narrow, snaking arms on the larger islands (Fig.4). These have undulating crests and varying widths, so that they are actually lines of contiguous cones (Fig.7). But these ridges are distinctly better defined than lines of partially connected cones in fengcong terrains (such as those in Java, Jamaica or China) that have not been drowned. They are not characteristic of karst, and it appears likely that they have a non-karstic origin. A fluvial origin could be



**Figure 3:** Drowned fengcong on the northern part of Ngeruktabel Island with lagoons and hong formed where the sea has invaded the dolines.

**Figure 4:**  
Features of the drowned karst of the northernmost of Palau's Rock Islands, immediately south of Koror.



due to superimposition of watersheds from a non-karstic cover, but there is no evidence that one ever existed over the limestone. The long watersheds could also derive from an early phase of fluvial erosion before karst drainage was established; the young, horizontal limestones have noticeably few open joints and the initial vertical permeability might have been low. Such a history is possible, but is unlikely on this scale and in the warm climates. A marine origin would appear to be more likely, with rapid coast erosion causing cliff retreat far faster than any contemporary karstic development of the landscape. Fluctuating sea levels in the Pleistocene, and fluctuating land levels when the underlying plate boundary was more active, offer scope for phases of aggressive marine erosion at varying levels on the now-drowned landscape. It has also been suggested that the long island ridges might inherit their linearity from the zones of maximum carbonate accumulation on what were once barrier reefs (Kellett, 1991).

All rainwater falling on the limestone sinks underground, and the scarcity of exposed basement means that there are very few risings. A bay known as the Milky Way, on the east coast of Ngeruktabel, is named after its milky waters that appear to have huge amounts of calcium carbonate in suspension above a shallow seabed that is a carbonate mud. This would appear to derive from mixing with a submarine input of spring water from one of the larger areas of sub-aerial karst, though the rock-boring chitons might also contribute with their clay-size excreta.



**Figure 5:** The eastern side of Mecherchar Island; Jellyfish Lake is the large hong with its waters darkened by the clouds of algae on which the stingless jellyfish feed.

## Caves in Palau

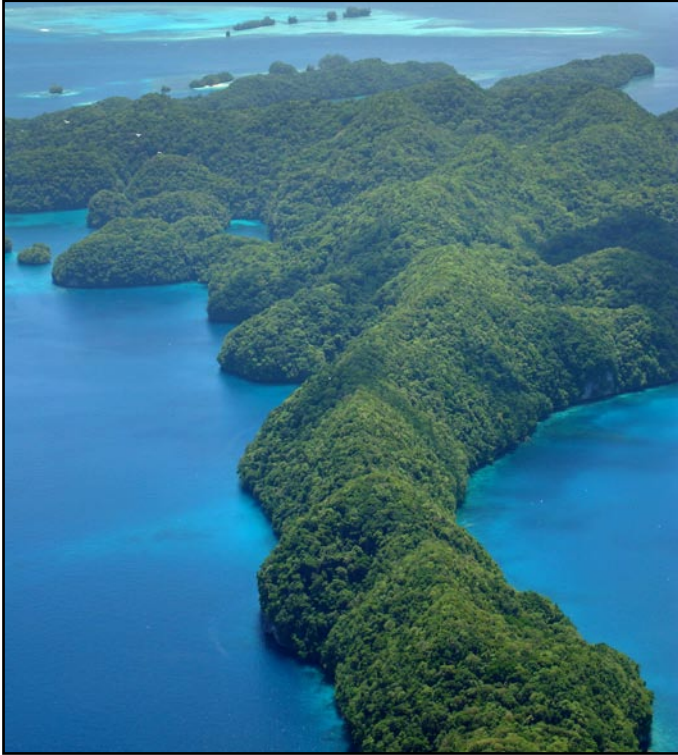
Even though these limestones, and their landscape, are young, it is likely that they are riddled with caves, but the thick forest cover has entrances well hidden, and most of the potential cave explorers are occupied instead with diving in the gin-clear waters.

A few small rock shelters on Koror and Babeldaob have had their flowstone floors quarried to manufacture the ludicrously large discs that the Yapese used for money in past centuries (Fitzpatrick, 2003). Three of these caves are described as truncated passage remnants, but there is no record of open continuations. One cave on Koror, on the east side of Nikko Bay, is currently being explored after its large entrance was exposed by falling trees and then seen from the air high in the hills and far from any easy access.

With their interiors little explored, most known caves lie round the coasts of the limestone islands, where they are accessible and easily visited by kayak (Fig.8). More than 25 caves recorded in the coastal cliffs are single chambers or short remnants of old, truncated caves. The half-flooded chamber of Skylight Cave has walls decorated with stalactites and a roof collapse through to daylight (Fig.9). Colossal Cave, on Ngeruktabel, is one of the few with an abundance of stalagmite and flowstone in galleries that rise beyond the first water chamber. No speleothems have yet been dated, but stalactites continue to depths of more than 10m below waterline in Cathedral Cave (Fig.10), and must



**Figure 6:** A deeply recessed marine notch cut into the limestone round the calm waters of a doline lagoon in the southern coastline of Ulebsechel Island.



**Figure 7:** The line of contiguous conical hills that protrude from the sea to form the long peninsula on the west side of Ngeruktabel Island.

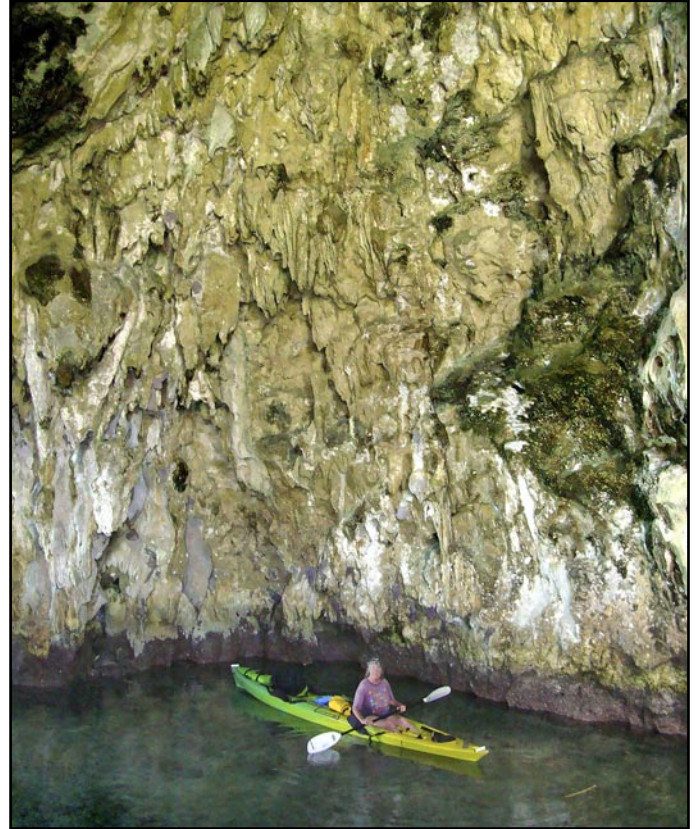
therefore date from a Pleistocene cold stage with declined sea level. Blue holes are also reported by divers, with some reaching to 40m deep, and others having exits out through the reef wall.

At least eleven of the hong lakes have cave passages that link them to the sea, and some of these are 100m or more long, but few are easily accessible. Some lie at the back of the marine notches, and can be passed at low tide, but are submerged at high tide. Others are permanently submerged, and passable only by divers. Long Lake stretches for more than 2km close to the eastern coast of Ngeruktabel. A narrow channel at one end is almost choked with mangroves, but is accessible by kayak around high tide. At the other end, a cave over 100m long is the only link to the sea; submerged at high tide, it carries fast flows of tidal water in and out of the nearly enclosed hong lake, so that it is only safely traversed during short intervals when the tidal currents slow and reverse.

There are clearly many more caves to be explored in Palau, but most will have limited access by kayak or will be reached only by hacking through the thick forest cover on the limestone islands. Regardless of what caves may be found, Palau will always deserve greater recognition for its spectacular surface landscapes. The combination of forested islands, conical hills, dark honges, blue lagoons and hidden caves makes Palau's karst truly notable, and also very beautiful.



**Figure 8:** Half-flooded, unnamed cave that has been truncated in the wall of Risong Bay, on Ulebsechel Island.



**Figure 9:** The single chamber in Skylight Cave, accessible only by kayak.

#### Acknowledgements

These notes have derived from a single visit to Palau, which offered scope for extensive observation but included no detailed research. This modest understanding of Palau's spectacular topography benefited from discussions with Ron Leidich, who has probably seen more of the karst and caves than anyone.

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**Figure 10:** In Cathedral Cave's half-flooded chamber, stalactites and curtains hang above deep water with more stalactites hidden in its depths.