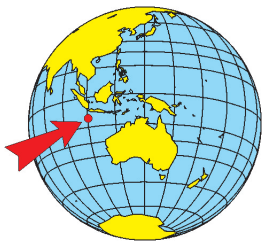
Christmas Island Karst

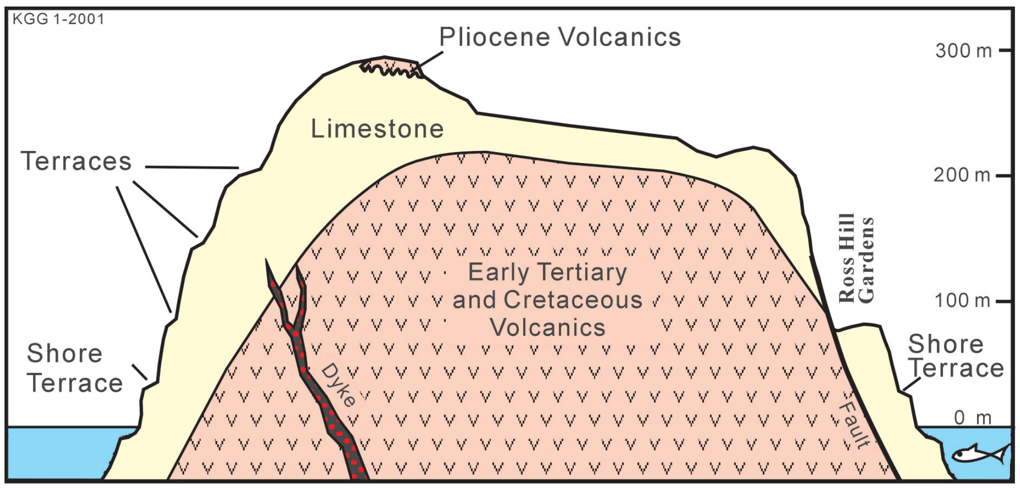


Geology and Topography

Location: Christmas Island is a tropical island (Latitude 10°30'S), in the Indian Ocean, northwest of Australia.

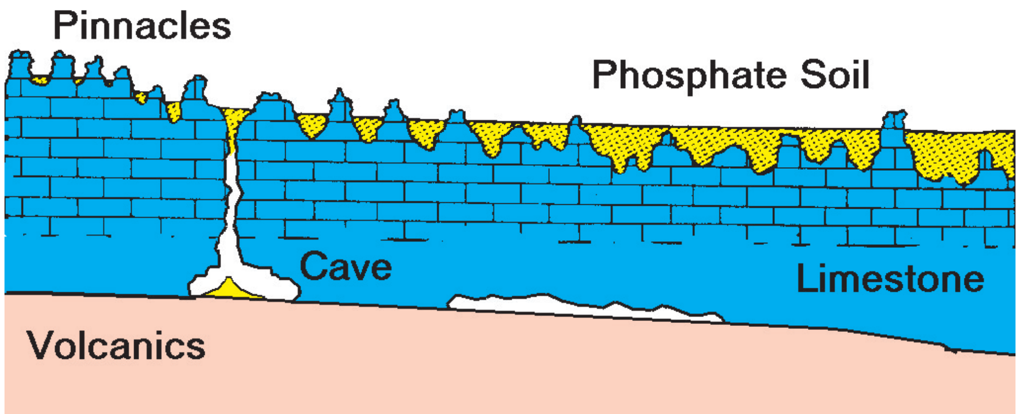
In 1998 a group of six karst-scientists spent two and a half weeks on the island, doing a study of the island's caves and karst for Parks Australia North - to assist them in preparing a management plan for the National Park which now covers a large part of the island.

The climate is tropical monsoonal with an annual rainfall of over 2000mm. However the rainfall is variable with a recorded minimum of 899mm and maximum of 3716mm. Tides have a spring-tide range of about 1.8m.

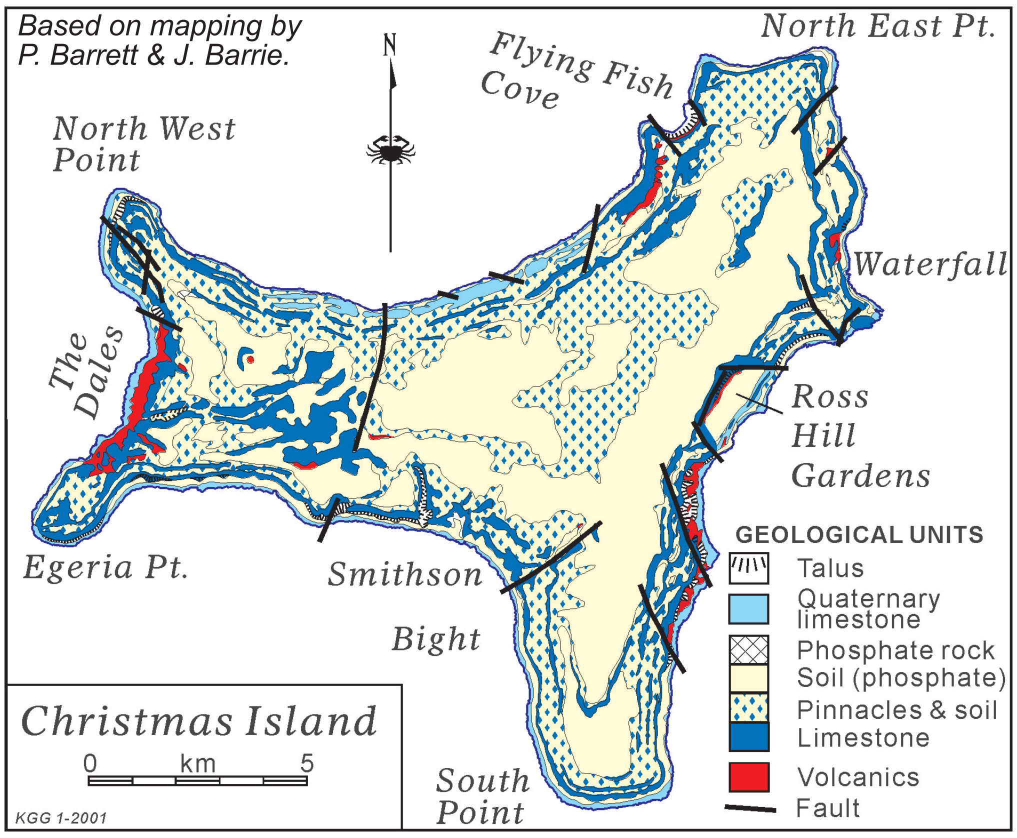


Diagrammatic cross-section of Christmas Island, showing volcanic core, limestone capping, and terraces. Vertical scale is exaggerated x10.

Terraces: The interaction of uplift and a sequence of old sea-levels has produced a series of terraces cut into the steep and cliffy limestone sides of the island. The lowest of these, *The Shore Terrace*, is from 50 to 200 m wide, and at an elevation of 20-40m ASL. It has been dated as last interglacial (124 ka) which is the basis for estimates of the uplift rate (Woodroff, 1988).



The central plateau (about 200-250m ASL, with hills up to 360m ASL) is phosphate over a pinnacled epikarst limestone surface, with the crest of the volcanic surface about 30-40m down.



Geology

The island is a seamont, consisting of a Tertiary, basaltic volcano with a mainly-Miocene limestone capping that is rising out of the Indian Ocean at a rate of 0.14 mm per year and drifting north towards Indonesia at 8 cm per year. The ocean floor is 4.5 km deep around the island.

The limestone is a hard, massive, marine, micritic calcarenite with scattered corals. It has little primary porosity but is locally well-jointed.

Palaeokarst breccias: Brecciated zones and pockets were seen in several caves. The Pliocene volcanics bury an old karst surface.

Phosphate caps most of the plateau, and has provided the main source of income for the history of the island. It is a soil concentration derived from either bird guano or an older lagoon deposit.

Normal faults cut the island, in places forming piano-key blocks at the margins. The caves show joint control, but directions vary across the island.

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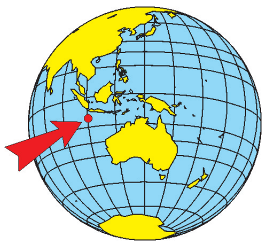


Surface Karst features

Surface karst features include:

Subsidence and collapse dolines on the plateau surface, and on some terraces,

The Dales are a set of narrow ravines cut into the *Shore Terrace*.

Springs, mostly near the island margins,

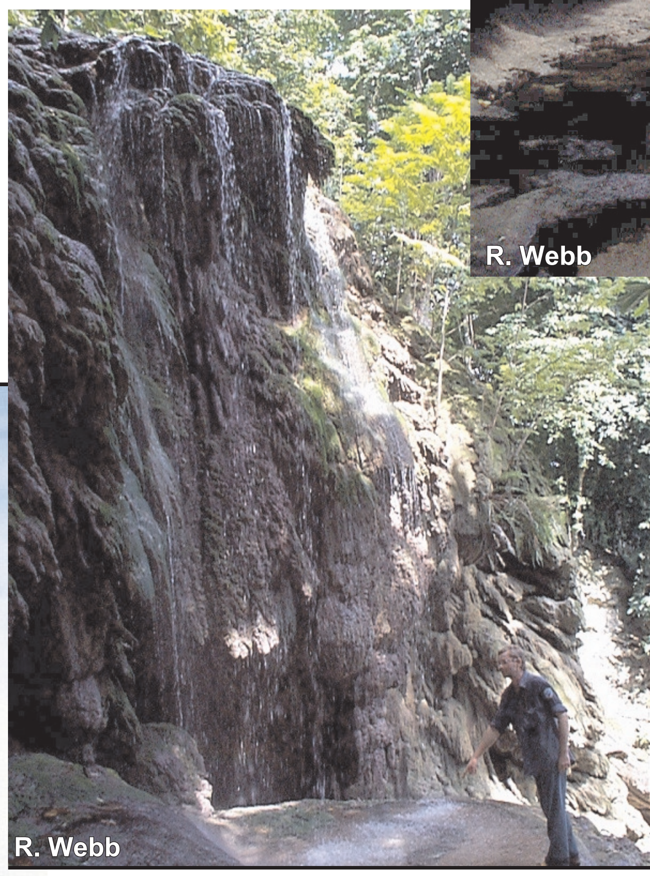
Tufa deposits associated with springs and waterfalls,

Karren (including phytokarst) on coastal and inland cliffs and outcrops,

Notches at the base of coastal cliffs, and

Pinnacles that developed at the soil-limestone contact, but have been exposed by soil erosion or mining.

One of The Dales: Is this an incised surface stream or a collapsed cave passage ?



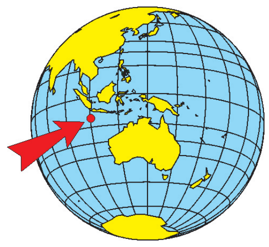
Tufa deposits on a waterfall in The Dales area.

Phytokarst on the Shore Terrace. The sharply-sculptured surface results from a combination of sea spray and etching by algae and other organisms.

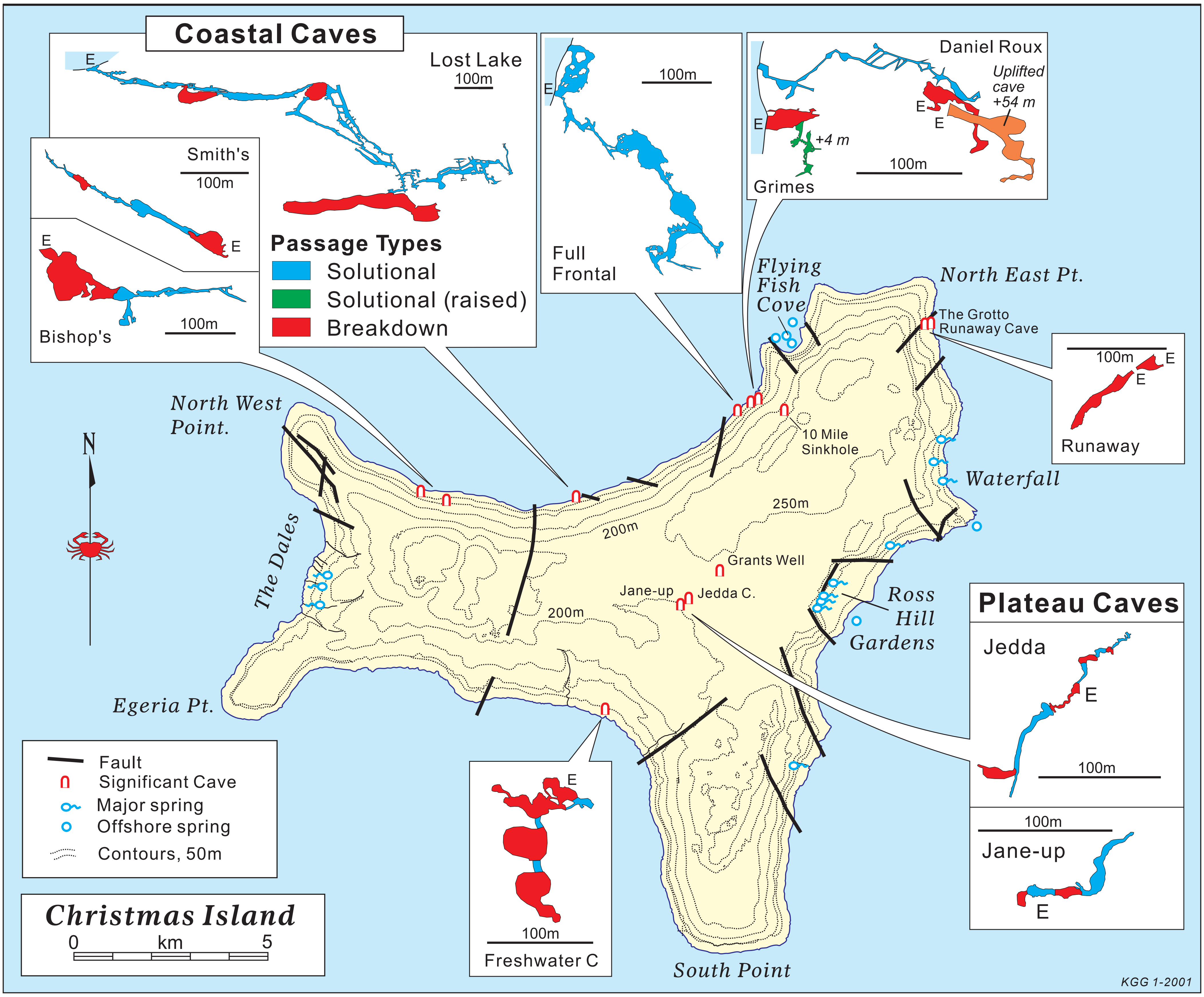
Coastal notches such as this are characteristic of all tropical limestone coasts.

The Sea Cliff (3-40m high) surrounds most of the island. Above it is the *Shore Terrace* and behind that an older raised sea cliff. Higher terraces and cliffs are less well-defined.

Christmas Island Karst



The Caves *(overview)*



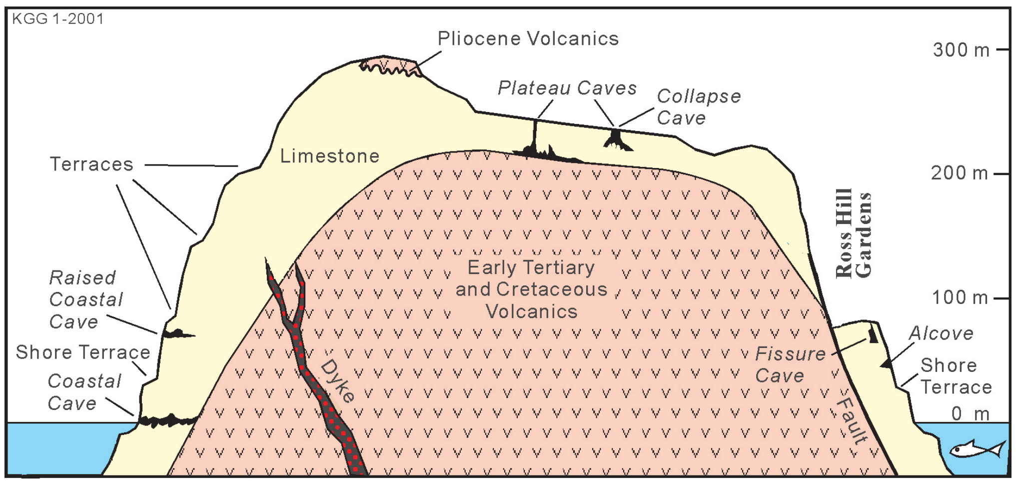
The Caves

The **coastal caves** lie at present sea level and are horizontal joint-controlled passages with irregular, sharp, spongework walls. At intervals they are punctuated by massive breakdown chambers.

Higher up one finds **uplifted coastal cave** systems that formed at past sea levels.

The few known **plateau caves** are different: Smaller, muddy, horizontal stream passages run at or not far above the limestone-volcanic contact, and are entered via vertical shafts or collapse dolines.

There are also **fissure caves**, behind and parallel to cliff faces, that seem to be at least partly the result of mass-movement. One unusual cave is developed **in basalt**.



Christmas Island Karst

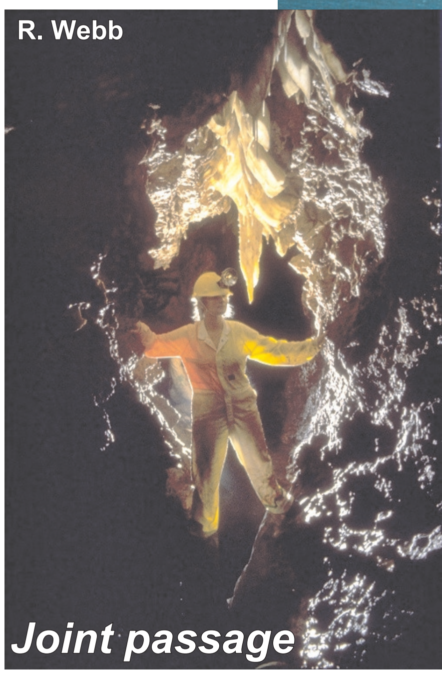
Coastal Caves

The coastal caves lie at present sea level. The longest has 2.5 km of mapped passage, and many unexplored leads. Most of these caves have strong outflows of fresh water.

These caves are horizontal joint-controlled passages with irregular, sharp, spongework walls. At intervals they are punctuated by massive breakdown chambers. Some caves are now dominantly breakdown with little of the original passage visible.

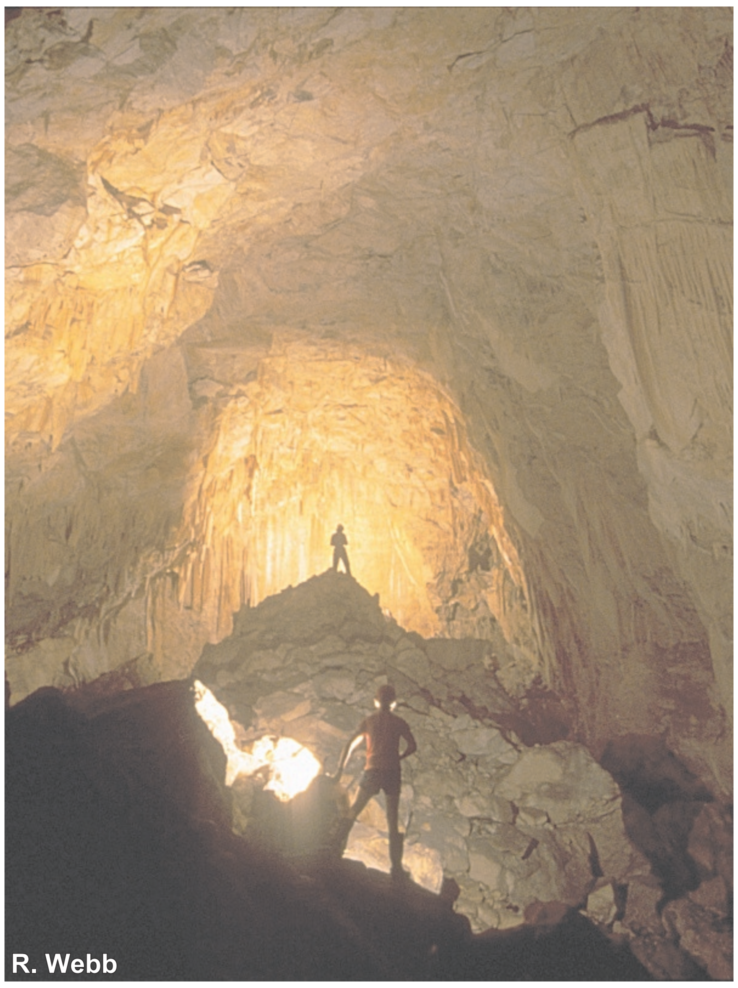
Cave entrance in the Sea Cliff

Spongework



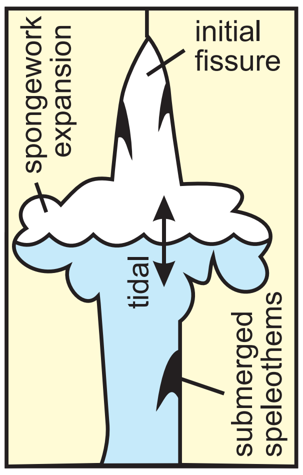
Joint passage

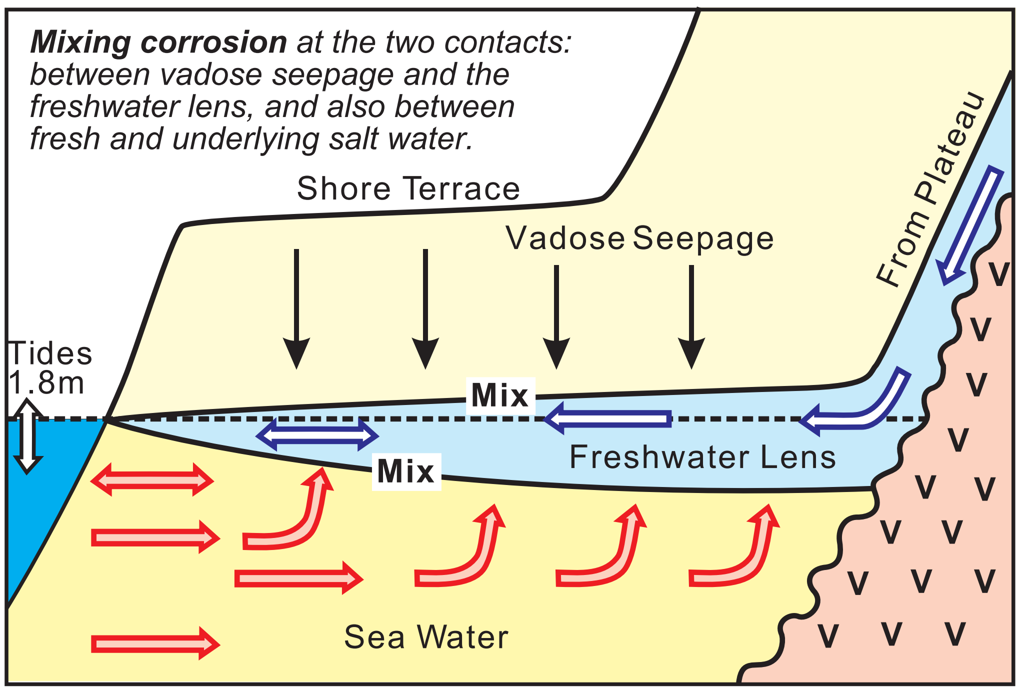
Collapse Dome



Mixing Corrosion

Within the coastal caves a fresh water lens is floating on sea water, so salt & fresh-water mixing-corrosion will be active and responsible for the extensive spongework sculpturing. Tidal mixing and flushing may also assist in the solution of the limestone. The impermeable nature of the rock has restricted the original passages to the joints, but spongework cavities are actively expanding from these.



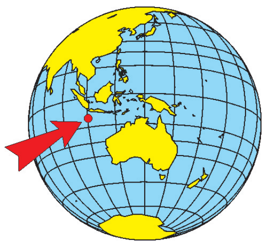


Earlier Events

The presence of **submerged speleothems** down to at least 6 m in the main flooded passages suggests that the original cave development predates the present Holocene highstand of the sea (see other panel).

Several caves have irregular pockets of **palaeokarst** breccias exposed in the walls; these are strongly cemented and very hard. Possibly they could date back to prior karstic events during the periods of low sea-level of the Pliocene, or even the late Miocene.

Christmas Island Karst



How long has the island been land?

This is the question asked by the biologists, who are interested in the rates of evolution of the cave faunas. The data is limited, but we can make some suggestions.

The Data

We know that the island was submerged during deposition of the shallow-marine limestones, i.e up to the end of the mid-Miocene.

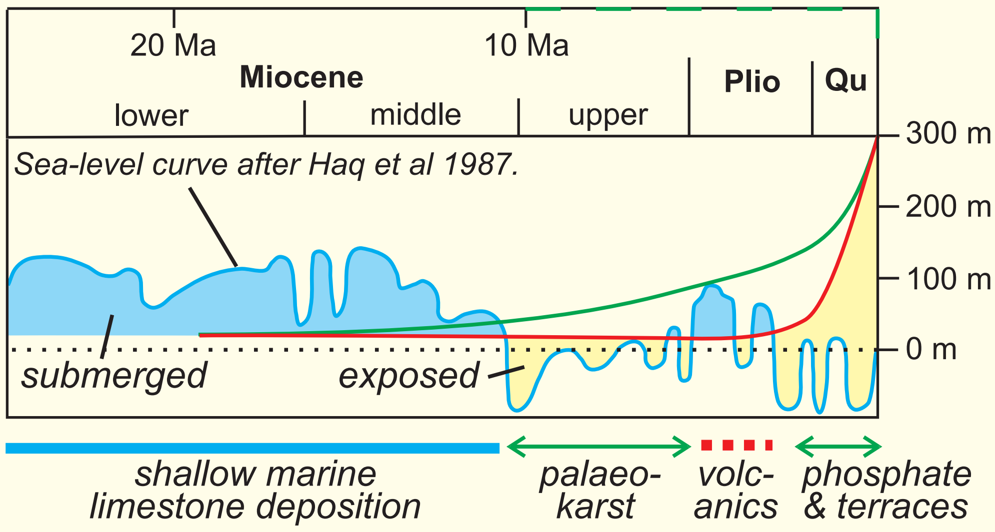
The Pliocene volcanics bury a karst surface - so the island was land prior to then.

The Pliocene volcanics (dated at 3-5 Ma) include some subaerial tuffs.

There are no recognised Pliocene or younger marine deposits - apart from the low-level Shore Terrace.

The present uplift rate is known from elevation and dating of the Shore Terrace - but must have been slower in the past to allow emergence during the Pliocene.

We have a sea level curve for the Tertiary and Quaternary (but the absolute elevations are poorly controlled).



Past sea-levels and uplift scenarios. The red and green lines are alternative possibilities for the height of the crest of the island.

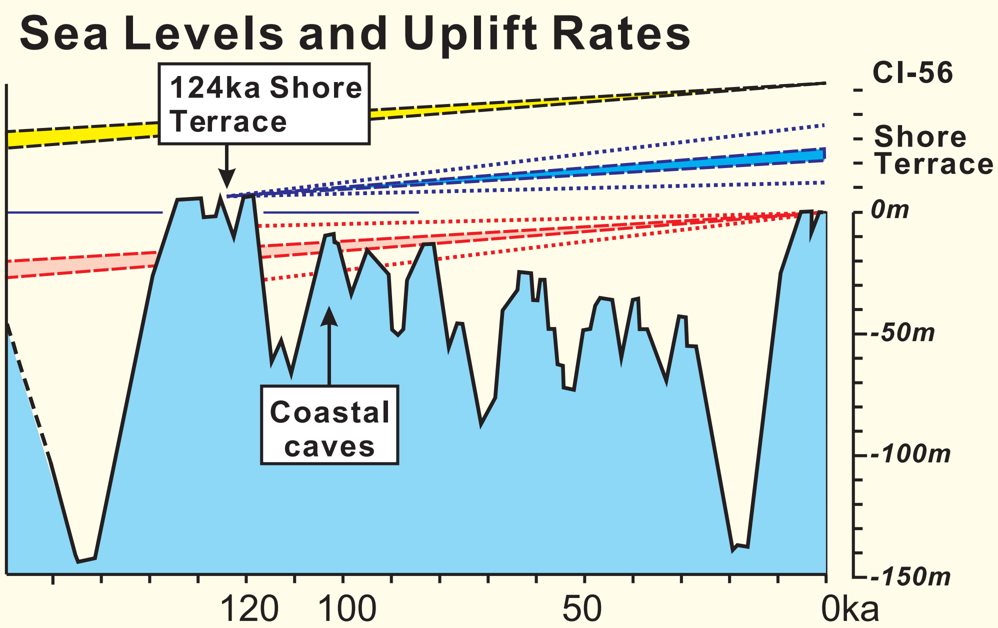
Interpretations

As shown on the diagram, we can extrapolate the level of the top of the island back in time using the present uplift rate and the evidence for times when it was definitely exposed.

The paucity of evidence allows two possible scenarios. In one the island may have been submerged during the Pliocene high seas, in the other the top of the island (at least) may have been dry for the last 10 million years.

The Age of the Caves.

For the **plateau caves**, karst solution would have commenced as soon as the plateau was exposed above the sea (see "How long has the Island been land").



The blue lines show the calculation of uplift rate from the age and present height of the shore terrace (the solid line is the best estimate, dotted is the extreme range). The red line extrapolate this rate back from the present coastal caves and the yellow extrapolates back from the height of a raised coastal cave (CI-56).

The present and uplifted **coastal caves** appear to have formed by mixing corrosion at contemporary sea-levels. So, to estimate their age, we must match uplift rates to old sea levels.

The present coastal caves have actively dissolving spongework superimposed on an earlier fissure form that has submerged speleothems. They intersect the limestones of the 124 ka Shore Terrace, so must be younger than that. The submerged speleothems point to a period of draining of the passages - when sea levels were lower during the last glacial period. The diagram extrapolates the uplift rates back to intersect the sea level curve at three possible high stands, the most likely being that between 101 and 104 ka ago (isotope stage 5c).

An **uplifted coastal cave** (CI-56) lies at an elevation of 54 m ASL, and if we apply the uplift rates this could correspond to the high-sea stand of an earlier interglacial about 330,000 years ago (isotope stage 9).

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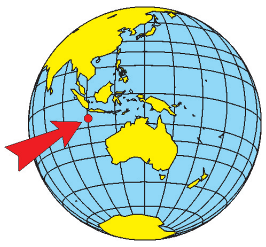


Karst Hydrology and Water Supplies

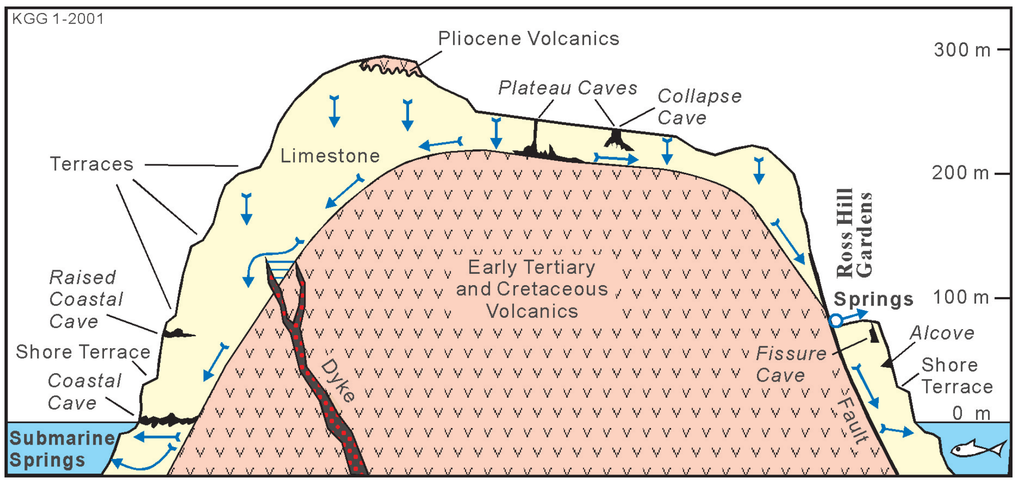
Plateau waters

The main water table under the plateau is just above the limestone-basalt contact and fluctuates seasonally. However, Barrett (1985) concluded that major water storage occurs in the epikarstic phosphate & soil zone above the limestone and that the water moves down from there through fractures and solution holes in the limestone to the volcanic contact. From there it moves in conduits along the contact. Drilling has indicated that there is little water obtainable from the matrix porosity away from these isolated conduits.

From the plateau the water then flows outward and downward to the sea through karst conduits along the surface of the volcanics. This is evident from the common occurrence of springs or seepages where the contact of limestone and basalt is at or very near the ground surface. In places the descending water has been dammed behind dykes to form local reservoirs.

Coastal waters

At the edge of the island the water table is at or just above sea level. In some caves the fresh water is floating as a lens above sea water; in others the two appear to have mixed to form brackish water. Outflow occurs through coastal caves and submarine springs.



Cross-section showing water flow lines (blue arrows) and caves. Vertical scale exaggerated x10.

Flow behaviour

Barrett (1985) reports that conduit flows in the plateau caves show marked seasonal variations. There is a lag in peak flow behind rainfall that averages 3 months, but varies from 1 month (following a wet 'dry' season) to 5 months (following a long dry season). Thus conduit flow only increases after the surface epikarst aquifer has been recharged at the start of the wet season.

The coastal springs were monitored in two places, both 20 m ASL at the back of the Shore Terrace. These springs were relatively steady - suggesting dominantly matrix flow.

The springs at Ross Hill Gardens, at about 120m ASL, have a behaviour part way between the plateau streams (at 200 m ASL) and the coastal springs. They are moderately variable and the peak flow lags 2 months behind the rainfall.

Human Exploitation of Karst Waters

A well-captured spring!

The search for water for the settlement and for mine operation was the main motivation for the early cave exploration, and also for an extensive program of geophysics and drilling on the plateau. The latter program had little success and most of the present supply is pumped from conduit streams within the plateau caves and from springs at Waterfall and Ross Hill Gardens.

The pump-house at Ross Hill Gardens. Biologists sampling for underground aquatic fauna

Karst Biology

The subterranean environment of Christmas Island is diverse and includes freshwater, marine, anchialine, and terrestrial habitats. The cave fauna is significant in an international context. The cave fauna and habitats are sensitive to disturbance from a number of threatening processes, including pollution, deforestation, mining, feral species and human visitors.

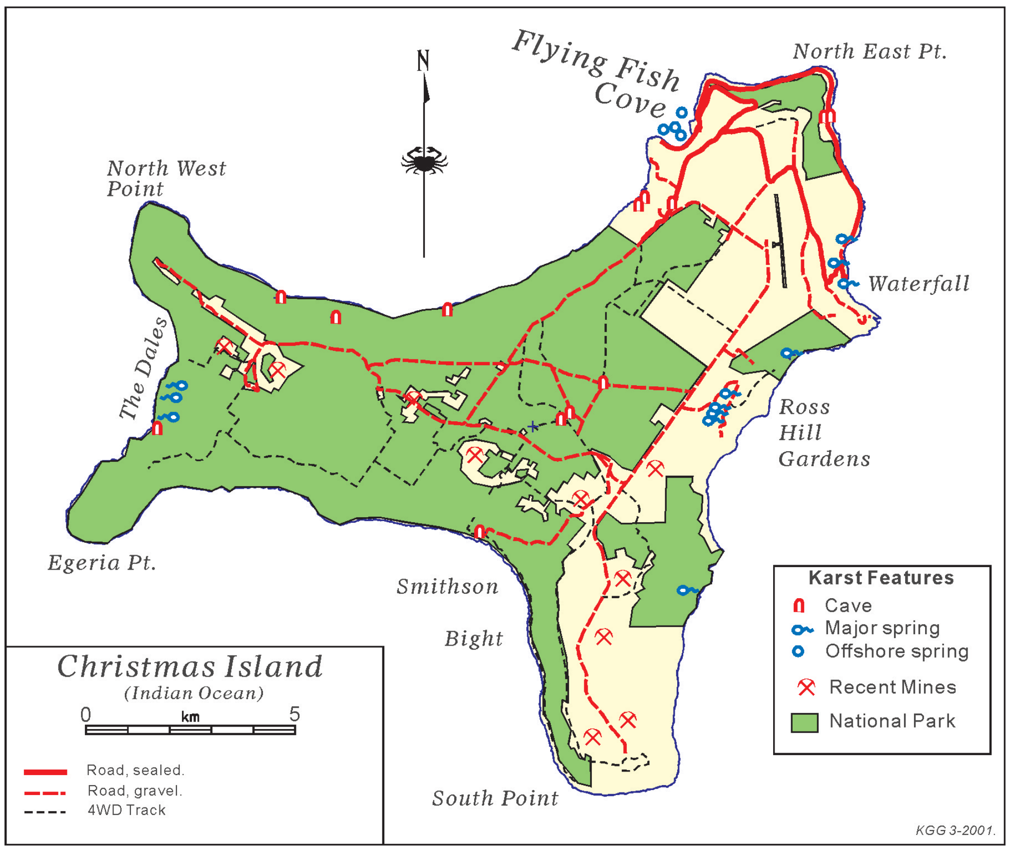
Whip Scorpion
(A.P. Spate)

Management

The phosphate mining will wind down in a few years, and alternative sources of income are needed - tourism seems the best option. Many caves are used by Island residents for recreational pursuits, but there are no organised tours to the caves apart from ocean diving trips which include some of the submerged or partly submerged coastal caves. A local caving club has been formed, but its future will depend on the continuing presence of dedicated leadership.

About 68% of the Island is currently National Park. The management is concerned about risks associated with cave visitation, especially in the partly-submerged coastal caves, which are tidal and have to be entered by swimming in from the sea. Foul Air in the plateau caves, and unstable rubble could also be a hazard.

There has been some dumping of rubbish and construction materials into dolines and cave entrances, and one doline (which is reported to have lead to an unusual pseudokarst cave) has been completely filled in and lost.



Water pumping from the plateau caves has involved the installation of pumps and sumps within one cave streamway, together with access steps, an entrance gate and fencing of the doline. Many springs have been concreted in.

The development of show caves is not considered appropriate at this stage. Only one cave lends itself to this style of development and, apart from the dubious economics, there is a conflict with the current usage of that cave as a swiftlet breeding site. Some caves could be developed for "wild-cave" tours with a minimum of modification. Others need to be managed for recreational visits by addition of cautionary signage and track-marking.

Hazard! Tidal, swim-in entrance (in calm weather!).