Moorea: Geography, Geology and Coral Reefs

The island of Moorea (Eimeo) lies 15 miles (25 km) northwest of Tahiti, at 17°30' S latitude and 149°50' W longitude. These two islands are the largest of the Windward group of the Society Islands (French: Iles du Vent) along with the much smaller islands of Maiao and Mehetia, and the atoll of Tetiaroa. The Leeward Islands (Iles sous le Vent) consist of Huahine, Raiatea, Taha'a, Bora Bora and Maupiti, and the atolls of Tupai, Mopelia, Scilly and Bellinghausen (Galzin and Pointier, 1985).

The Society Islands are one of five island groups that make up French Polynesia. The Tuamotu Islands (or Dangerous Archipelago) consist of 77 atolls spread out over 1000 miles (1600 km) of ocean mostly east of Tahiti. The Gambier Islands represent a single reef system at the eastern end of the Tuamotus. The 14 high islands of the Marquesas lie to the northeast, and the six Austral Islands lie to the south (Saquet 2000).

Polynesians arrived in these islands about 600 AD (although earlier dates have been proposed). Over the next 1000 years the Polynesians on Tahiti and Moorea developed their own culture and language, distinct from the other island groups. At various times parts of both islands were ruled by a common king, although local chiefs tended to rule their own portions of one or the other island.

Europeans first arrived in Tahiti on board the HMS Dolphin on June 23, 1767. Capt. Samuel Wallis and crew landed at Matavai Bay, near what would later be called Point Venus. They stayed only a few days, but had time to trade, battle, and appreciate the local costume. Louis Antoine de Bougainville came next: April 6-14, 1768. He anchored on the eastern side of
the island, which he claimed for France (a claim made good since the mid 1800's until today).

Captain James Cook made four visits to Tahiti. The first, in 1769, was to measure the Transit of Venus on June 3 of that year. He went to Matavai Bay after hearing about Capt. Wallis's visit. His men erected a fort on Point Venus (hence the name) where their observations were made. Others of his crew simultaneously took measurements from a motu on Moorea. He later mapped both Tahiti and Moorea, and visited the other Society Islands.

Captain Bligh and the HMS Bounty arrived in 1788 to bring breadfruit to the New World as a cheap source of food for slaves. [After the famous mutiny Bligh returned to Tahiti and did bring breadfruit to the Caribbean, where the slaves refused to eat it.] The Voyage of the HMS Beagle (1831-1836) brought Charles Darwin to French Polynesia. He wrote a book on coral reefs based on this trip that describes reefs and their formations, particularly atolls.

Today, two university research facilities provide housing, labs, boats and dive gear for students and scientists on Moorea. L'Ecole Pratique des Haute Etudes has administered the Centre de Recherches Insulaires et Observatoire de l’Environnement (CRIOBE) at the base of Opunohu (Tahitian: belly of the stone fish) Bay since 1980. The University of California, Berkeley administers the Richard B. Gump South Pacific Research Station, at the mouth of Pao Pao Bay (Cooks Bay) since 1985.

**Island Formation**

The islands of French Polynesia were initially formed by hot spots: geologically active spots beneath the Pacific Plate. These hot spots
periodically spew forth magma to form volcanoes; they can grow from the ocean floor and eventually emerge above sea level. Because the Pacific Plate is in motion, an individual hot spot can generate a series of volcanic islands in an arc as the existing islands are carried away from the hot spot. This process can explain the nearly linear arrangement of these islands. [Note: The Hawaiian Islands were formed the same way. A newly formed submarine volcano is active southwest of the big island of Hawaii: Loihi.]

The arrangement of islands within a group also suggests their relative age. Tahiti is often thought of as the youngest of the Society Islands (approximately one million years old), although the much smaller Mehetia island lays Southeast of Tahiti and continues to spew lava, so is still growing. Moorea is somewhat older (1.5 million years old). Both of these islands are considered high islands because their volcanoes still protrude above sea level. However, the vast bulk of these volcanoes push down on the underlying crust, and these islands are gradually sinking - a process called subsidence. Maupiti and Bora Bara lie at the other end of the Society Islands. They are much smaller both in area and elevation, and are millions of years older (see table). They are still considered high islands, however, because some portion of the original volcano remains above water within the lagoon.

Moorea is surrounded by a barrier reef that protects the island and its lagoon from the wave energy of the Pacific. The barrier reef lies about 0.6 miles (0.5-1.5 km) from the shoreline, creating an extensive lagoon system of shallow, calm water. By comparison, the reef around Tahiti is not nearly so well developed, in part due its younger age. Bora Bora, although a smaller island, has a larger lagoon system (depth and width) compared to Moorea.
Charles Darwin described these high islands as well as the many atolls he visited. Atolls consist of narrow strips of land, (motus in Tahitian) only a few meters (about 10 feet) above sea level, and a central large, often deep lagoon. From these observations Darwin hypothesized that atolls were the product of 1) subsidence of a volcanic (high) island, and 2) the continued growth of the coral (barrier) reef on the original edge of the volcano.

“After the details now given, it may be asserted that there is not one point of essential difference between encircling barrier-reefs and atolls; - the latter enclose a simple sheet of water, the former encircle an expanse with one or more islands rising from it. I was much struck with this fact, when viewing, from the heights of Tahiti, the distant island of Eimeo [Moorea] standing within smooth water, and encircled by a ring of snow-white breakers. Remove the central land, and an annular reef like that of an atoll in an early stage of its formation is left; remove Bolabola [Bora Bora], and there remains a circle of linear coral-islets crowned with tall coconut trees, like one of the many atolls scattered over the Pacific and Indian oceans.”

Charles Darwin, The Structure and Distribution of Coral Reefs

Illustrations on the next page show three types of tropical island: a) high island with fringing reef, b) high island with barrier reef, and c) atoll. Darwin’s hypothesis suggests that these three forms are stages. Initially a volcano is formed and cools to the point that coral can settle on its shoreline, creating a fringing reef. As the volcano subsides, the shoreline recedes, but the live coral continues to grow at its initial location. This reef is now considered a barrier reef. Eventually the volcano sinks entirely beneath sea level, with only the reef left around the lagoon = an atoll.
Sequence of Coral Atoll Formation from a volcanic High Island
Darwin's hypothesis of atoll formation was eventually supported when nuclear bombs were tested at Enewetak Atoll in the 1950's. As they drilled deep into the reef, volcanic rock was discovered underneath 1400 m (4,600') of limestone (calcium carbonate) the skeletal remnants of corals.

Reef Formation

Coral reefs are formed in large part by a group of animals known as corals (P. Cnidaria). Corals feed mostly on plankton. However, they also receive energy from photosynthetic symbionts (below). **Hard corals** create a skeleton of calcium carbonate (limestone). Most hard corals are colonial, consisting of thousands of polyps. As they grow, they lay down calcium carbonate in layers, somewhat like the rings of a tree. As they grow up and over earlier layers, they may create a massive structure. In combination with other coral colonies, and **coralline algae**, they form a coral reef.

**Coralline algae** also secrete a calcium carbonate skeleton. Green algae (P. Chlorophyta) in the genus *Halimeda* may produce more limestone than all corals combined. Several species of red algae (P. Rhodophyta) use calcium carbonate in their skeleton. More importantly, coralline red algae cement together the dead calcium-carbonate skeletons of corals and *Halimeda*, as well as the shells of clams and snails (P. Mollusca) to create the overall reef.

Most **hard corals** also require the help of single-celled algae known as **zooxanthellae** (P. Dinoflagellata). These algal cells live within coral cells (endosymbionts). They provide corals with a source of energy: the sugars from photosynthesis. The corals provide a safe place for the zooxanthellae to live and also contribute nitrogen from their wastes. Thus, these two organisms share a **mutualistic symbiosis**. The photosynthetic pigments of
zooxanthellae also give corals their color. Without them, corals appear white or bleached. Bleached corals are stressed, often incapable of further calcium carbonate secretion, and may die. Finally, because most hard corals need their photosynthetic endosymbionts, these corals can only grow in clear, shallow water where light can penetrate.

As mentioned above, Moorea is a classic high island surrounded by a barrier reef and lagoon (more on reef subdivisions below). In addition, there are several passes through the reef as well as motus (islets) just inside of the reef, particularly near passes. These features are created mostly by abiotic (non-living) factors.

Passes are deep channels through a barrier reef - usually deep enough for large ships to enter the lagoon system. Their formation was a problem from the time of Darwin. Two processes currently explain them: 1) corals cannot grow in fresh water, and 2) sea-level has changed dramatically over recent geological time. In particular, sea level during the last ice age (about 12,000 years ago) was 140 m (450') lower than it is today. On the north shore of Moorea are two large bays (Pao Pao and Opunohu), each with a pass opening through the reef approximately 100’ deep. At the base of each of these bays are rich river valleys. While the rivers are an obvious source of freshwater, the bays are nearly as salty as the open Pacific. Thus, the river water has little direct effect on passes today. However, when sea level was much lower, the current 'bays' would have been extensions of the river valleys, running right through the current location of the passes - they may have been extraordinary waterfalls. As sea level rose with the melting of ice sheets, coral continued to grow on top of the barrier reef, but not where
the river continued to flow. Eventually, as the pass became deeper, less light reached the bottom of the pass, limiting coral growth, even as the bays became more saline. Thus, the passes remain as an opening in the reef.

Motus form from the calcium carbonate skeletons of the reef. The force of wind and waves constantly attack the reef, occasionally breaking off pieces of coral. These broken bits either roll down the face of the reef, or they are pushed across the top of the reef (the reef crest) and deposited within the quieter waters of the lagoon. As materials accumulate within the reef, they may pile up above sea level. At this point, a combination of wetting by waves and rain, and drying in the tropical sun, create chemical reactions that cement bits of coral, coralline algae, and shells together to form beach rock. Over time, enough material can accumulate to trap sand and provide enough 'dry' land for coconuts to grow. Motus can continue to grow over time. In atolls, they are the only 'island' left after the volcano has subsided. Note the different ages of the parts of Moorea and its reef system: volcanic origin about 1.2 mya, passes formed around the ice age (12,000 years ago) and motus more recently developed since the time of modern sea-level.

Coral Reef Biology
Coral reefs represent the most diverse of marine biomes and the largest structures built by living things on Earth (the Great Barrier Reef off Australia is larger than the Great Wall of China). As noted above, corals and coralline algae build the reef itself. They create a complex habitat that provides homes and refuges for many types of organisms, as well as food for the many animals on the reef. [Refuges and food are commonly thought to be
limiting resources.] The open ocean also brings a steady supply of plankton (drifters) to the reef: both phytoplankton and zooplankton (mostly single-celled algae and small animal drifters, e.g. copepods). Collectively, the coral, algae and plankton provide food for the diverse taxa of animals, often grouped into feeding guilds: herbivores, planktivores, and many types of carnivores.

Three abiotic factors typify coral-reef biomes. The waters are: 1) warm, 2) clear and shallow, and 3) low in nutrients. Each of these factors directly or indirectly effect corals, and so the entire community.

1. **Warm temperature**: hard corals are found in waters with an average temperature of 20°C (68°F) or higher. Hard corals simply do not grow well in cooler waters.

2. **Clear, shallow water**: the zooxanthellae require sunlight for photosynthesis. Water absorbs light rapidly. Coral growth is greatest just below the surface, and drops off dramatically with depth. Very little coral grows below 30 m (100').

3. **Low nutrients**: coral reefs occur in tropical marine waters, which in general have very low concentrations of nutrients such as nitrogen. Low nutrients limit algae from growing in these waters, particularly large, multicellular seaweeds or macrophytes. By comparison, the nitrogenous waste of their coral hosts enriches the zooxanthellae within coral cells. Thus, coral grows well in this environment and can successfully compete for space on the reef. By comparison, waters with higher nutrient content give algae a competitive edge and they can overgrow coral. For example, pineapple farms on the hillsides around Pao Pao Bay lead to erosion that provides nutrients for algae.
Reef Structure

Barrier reefs can be divided into several habitats or zones. The **Forereef** (or **Fore-reef slope**) faces the open ocean, a constant source of new food. It may be relatively steep, depending on winds, waves and age. The rich supply of food and depth gradient create the conditions for the greatest coral diversity. The **Reef Crest** lies at the top of the forereef. Here, waves constantly break across the reef limiting coral growth. However, the shallow waters provide the greatest sunlight for photosynthesis. Crustose coralline red algae and low growing corals often cover the reef crest. The area between the reef crest and the island is generally referred to as the **lagoon**, although many terms are used for subdivisions of the lagoon, and others define the lagoon as only the deeper waters within the reef.

Just inside the reef is a **Rubble-zone**: a narrow area full of coral pieces broken by the waves. Small **black tip reef sharks** commonly cruise the rubble zone hunting fish disoriented by the waves. The rubble-zone lies next to the **Backreef** or **Reef flat**, a shallow area (usually less than 3m/10’
deep) mixed with corals and sand. The white sands of Moorea come primarily from the bioerosion of corals by grazers such as parrotfish. Black sand beaches, more commonly found on Tahiti, are volcanic in origin. Motus may be found in the back reef, close to the reef crest. Further toward the shore may be a deeper lagoon with patch reefs. The shore may be sandy, tree-lined or fringed with coral (fringing reef).

On the north shore of Moorea you will see all of these habitats with variations. Near the two bays, water flowing over the reef crest heads to shore and creates deep channels leading into the bays. Directly between the bays, the reef flat continues from the rubble-zone to a sandy shore without ever reaching depths over 3-4m. The shallow depths and incredible visibility of the reef flat make it a primary site for our explorations.

As we visit different parts of the reef, consider the biotic and abiotic effects. The forereef receives fresh sources of plankton and clear, nutrient-poor ocean water with few sediments to black the sunlight. Near shore, the lagoon receives nutrients and sediments from natural erosion and agricultural runoff. In addition, the rich oceanic plankton has been consumed by the ‘wall of mouths’ on the forereef, reef crest etc.

- Where would you expect to find the most coral? The most algae? Note: consumers of coral and algae will be found near their food source.

Besides providing a source of food for other animals, corals create diverse habitats for organisms to settle, burrow, and take refuge. As noted above, refuges (hidey-holes) are thought to be limiting resources for many marine organisms. A limiting resource limits the numbers of a population or
community. If more of the resource were added, more members of the population would be able to survive and reproduce. For example, artificial reefs placed over sandy bottoms attract new inhabitants and essentially create a new community. Coral provides the same type of resource.

We will first survey the reefs of Moorea in a single transect from the beach at Temae to the reef crest (see 'Moorea Island', Galzin and Pointier). Transects provide a simple measure of populations and communities. Although a variety of specific methods can be used, the general procedure is to swim (or walk) along a predetermined line and count or estimate the number of organisms, type of habitat, etc. along the transect.

As we swim this transect, you can measure distance by counting your kick cycles. For example, you might swim for 10 kick cycles and then take a 'measurement'. Your measurement might include some description of the immediate habitat: are you floating over sand? or coral? Or, within a 2 m circle with you at the center, is the circle mostly sand or coral? (How much of each?). In addition, you might keep track of some of the other organisms. Fish are easy to watch. How many types of fish do you see at this spot? How many of each type? Are they mostly white? Or variously colored?

Although it is difficult to plan methods of assessment for a biome you have never visited, creating even a simple plan and following procedures will limit the chances of a biased sample.

**Organisms**

Coral reefs contain the greatest species diversity of marine biomes, so a section on organisms can only highlight a few major groups and examples. **Prokaryotes** are too small for our surveys, although scientists increasingly
value their importance as both autotrophs (able to feed themselves), particularly the photosynthetic blue-green algae or cyanobacteria, and decomposers that recycle nutrients within the ecosystem.

Multicellular autotrophs on the reefs of Moorea are primarily algae: Rhodophyta or red algae are the most speciose in the tropics. Coralline red algae were discussed above for their contributions to reef structure. There are also many filamentous forms that are difficult to identify in the field. Some forms are farmed by damselfishes (more below). One form has been found in large patches in the bays recently, Actinotrichia fragilis (spikeweed) [my dive notes recorded this alga as Dasya pilosus]. Phaeophyta or brown algae include types of sargassum. The most common form we will see grows on the tops of dead coral heads, a species of Turbinaria. Green algae (Clorophyta) are mostly associated with freshwater, but some, like Halimeda are common in the back reef.

The other major photosynthetic groups are the unicellular eukaryotic algae: diatoms and dinoflagellates. Most of these are considered phytoplankton, although many forms are benthic (on the bottom) and zooxanthellae are symbionts of coral (and others).

All of these groups of algae provide food for the many heterotrophs (eat others) or consumers that live on the reef. Fungi are consumers and decomposers, but are difficult to survey. The rest of the organisms we are likely to see are the animals.

Many sponges (P. Porifera) live on coral reefs. These organisms are filter feeders, with simple body plans. Phylum Cnidaria includes the corals, as well as the anemones and jellyfish (medusae). Corals come in diverse shapes and sizes, from branching corals (e.g. Acropora and Pocillopora) to
the massive boulder corals (e.g. Porites). Branching corals can rapidly overgrow these slower growing massive types. However, branching coral is fragile, while some Porites heads have been aged at 300 years or more.

Jellies can be quite dangerous with their stings, although it is rare to find these forms in Moorea. New divers are much more likely to be injured by crashing into a coral and scraping themselves. The most spectacular anemone in Moorea is Heteractis magnifica with its mutualistic anemonefish (or clownfish) Amphiprion. Anemones, like corals, feed on other animals with special stinging cells. They also contain zooxanthellae for photosynthesis.

Many groups of worms occur in the reef, from diverse taxa. We may see some parasitic flatworms (P. Platyhelminthes) or roundworms (P. Nematoda) in the fishes we buy for dinner. These phyla also contain various free-living forms, but rare to be seen on snorkel. The most obvious worms live in coral heads with special filter-feeding structures exposed into the water column: tubeworms and Christmas tree worms (P. Annelida, C. Polychaeta). We may also see deposits of an acorn worm (P. Hemichordata).

Phylum Mollusca contains the most species of any marine group. Class Gastropoda – snails, are the most diverse. The large, seven-fingered conch, Lambis lambis feeds on algae, whereas the cone shell, Conus uses a poisonous dart to capture animal prey - beware! Other snails we will look for include the top shells (Turbo, Trochus) and cowries, F. Cypraeidae (once used as money). A variety of sea slugs (nudibranchs) can also be seen. They are colorful, lack a shell and many are poisonous to eat (we will not eat any). Other mollusks include C. Bivalvia: clams, oysters etc. and C. Cephalopoda: squid and octopus. Bivalves filter feed for a living: mostly on phytoplankton. Although prized as tasty treats, the reefs of Moorea still contain many
'giant clams', *Tridacna maxima*. Their colorful flesh contains zooxanthellae symbionts - that is why they open their shells during the day. Pearl farms grow *pearl oysters*, *Pinctada margaritifera* in many lagoons of Polynesia, but not Moorea. *Octopus cyanea* hunts during the day. It is relatively large, but difficult to see because of its ability to change color and shape. Look for odd behavior by fishes to find an octopus. Octopuses feed on crabs, other crustaceans and mollusks. Some may occasionally grab a fish.

**Crustaceans** (*P. Arthropoda*) include crabs, shrimp and lobsters, barnacles (and others) as well as the major groups of *zooplankton*: *copepods*, *ostracods*, and *krill* (*euphasiids*). These zooplankters play a critical role in transferring food from the phytoplankton to the many *planktivores* (plankton eaters) on the reef: corals, anemones, some tube worms, mollusks, other crustaceans (e.g. barnacles), some echinoderms, many fishes and even the great whales. *Alpheus* shrimp are common in the back reef. These shrimp create burrows and often live in symbiosis with *gobies* (fish). There are a variety of small shrimp and crabs that live on larger hosts. On the shore live *Grapsus* crabs, and along the roads and hedges live *land crabs*, or *tupa* (Polynesian).

**Phylum Echinodermata** (spiny skin) includes: *sea stars* (*starfish*, *C. Asteroidea*), *brittle stars* (*C. Ophiuroidea*), *sea urchins* (*C. Echinoidea*), *sea cucumbers* (*C. Holothuroidea*) and *sea lilies* (*C. Crinoidea*). *Sea stars* are carnivores on a variety of prey. The large *crown-of-thorns starfish*, *Acanthaster planci* devours coral, sometimes with explosive populations that devastate the reef. The *cushion star* or *pillow star* (*Culcita*) occurs throughout the backreef. Brittle stars often hide under rubble, rocks or
coral, extending their arms to trap plankton, or feed at night on eggs and detritus.

Sea urchins graze the surface of dead coral and rock for the algae that grows there. Urchins present the greatest danger to inexperienced divers. Diadema savigny (vana tararoa) has long, black spines that will readily break off in your skin. The shorter spines of Echinothrix diadema (vana tarapoto) will still puncture a diver with ease; they may be black or variegated (black and white). Pencil urchins, Heterocentrotus mammillatus (vana retue) do not pose a danger with their blunt spines (they make nice jewelry). Vana havae, Tripneustes gratilla, is the preferred urchin for the table with short white spines surrounding a purple body. Herbivores that eat algae, such as sea urchins and parrotfish, can have a significant impact on the health of coral reefs. Overfishing of parrotfish and the decline of sea urchins (disease) were associated with algae over-growing over coral reefs in the Caribbean Sea.

Sea cucumbers either filter feed with special mouth ports or pass large volumes of sediments through their gut digesting the thin layer of organic matter on the surface. Common in Moorea are the small black cucumber, Halodeima atra (roriere ere) and the larger ocellated cucumber, Bohadshcia argus (rori patapata) - beige with black spots. Other urchins have large, fleshy spines (Thelenota) while others appear long and snake like, with their mouthparts clearly exposed. Although generally harmless, picking up a sea cucumber can lead to the ejection of sticky, stringy material that may be toxic. Better to leave them alone.
Fish

Fish make up the majority of large active predators on coral reefs. We will devote several activities to observations of fish. A separate handout describes some of the more common fish we will see in Moorea.

References


