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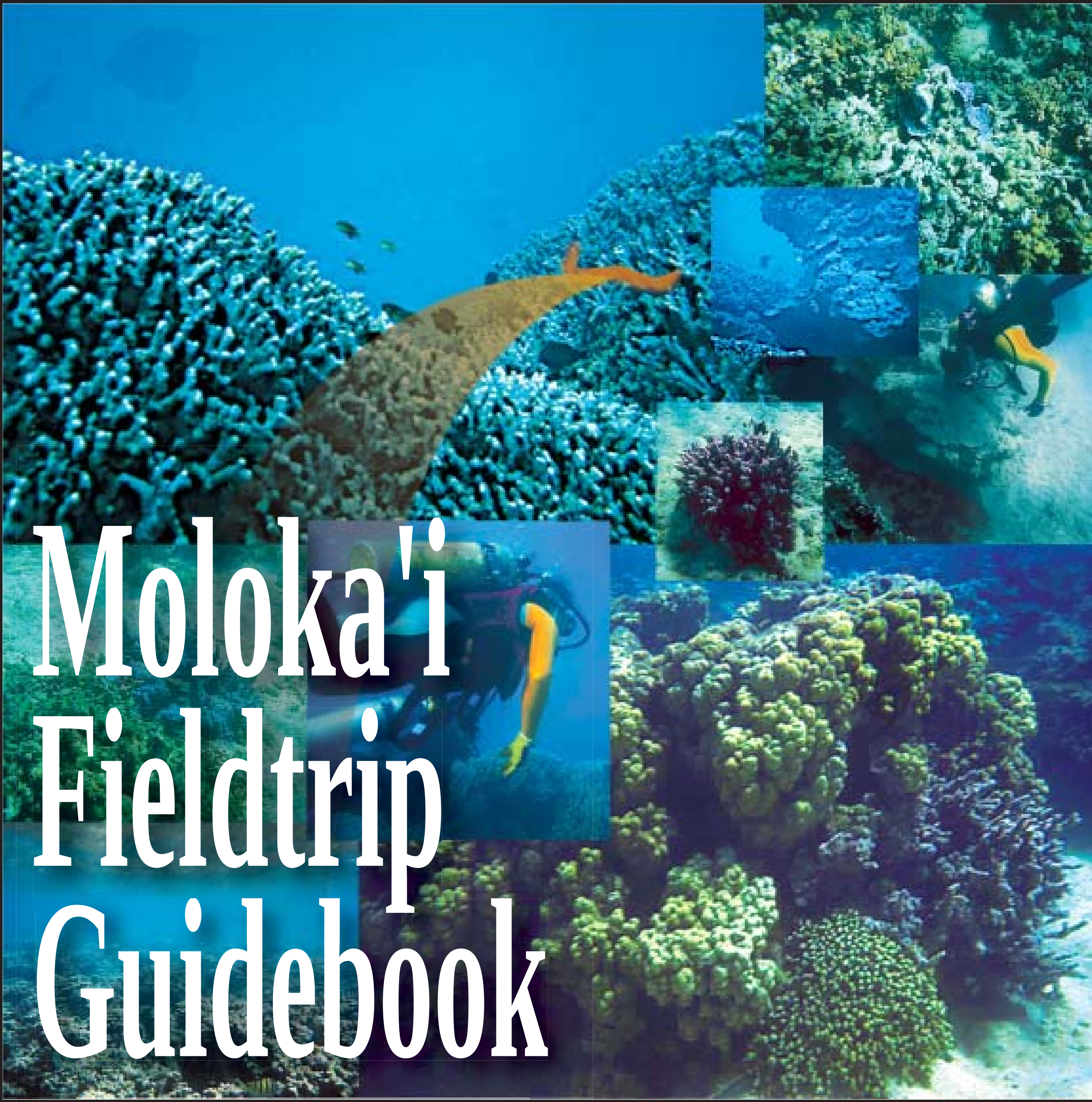

Moloka'i Fieldtrip Guidebook

Selected Aspects of the Geology, Geography, and Coral Reefs of Moloka'i

U.S. Department of the Interior
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Selected Aspects of the Geology, Geography, and Coral Reefs of Moloka'i

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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FOREWORD

This guidebook was compiled with the express purpose of describing the general geology of Moloka'i and those locations with significance to the U.S. Geological Survey's study of Moloka'i's coral reef, a part of the U.S. Department of Interior's "Protecting The Nation's Reefs" program.

The first portion of the guidebook describes the island and gives the historical background. Fieldtrip stop locations are listed in a logical driving order, essentially from west to east. This order may be changed, or stops deleted, depending on time and scheduling of an individual fieldtrip.

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Introduction

Coral reefs, large structures built by healthy communities of living corals, are some of the most biologically diverse and productive ecosystems on earth. However, these habitats are under risk in many parts of the world. American coral reefs are in peril for a variety of known and yet-to-be-discovered causes. It is well known that nutrification, sedimentation from dredging, and pollution harm living reefs near population centers. Reefs in remote areas are also declining through impacts of overfishing, sea surface warming, and local land-use practices.

As a part of the U.S. Department of Interior program, “Protecting the Nation’s Reefs”, the U.S. Geological Survey is participating in integrated studies to understand the linkages between coral reef processes and geologic growth and development. The Coastal and Marine Geology Program’s participation is focused on three activities: 1) thematic mapping; 2) reef health; and, 3) natural controls on reef health.

The southern coast of Moloka'i is bordered by one of the longest continuous fringing coral reef in American waters, some 60-70 km (35 miles) in length. Recent investigations of the Moloka'i reef system suggest that human activities, along with natural sedimentation and environmental change, may have affected the health of parts of this reef. The USGS selected this reef to study the technologies for producing detailed coral reef maps that are useful to managers and planners and for understanding the role of geologic processes in reef health.

The purpose of this background chapter is to describe the coastal habitats of Moloka'i, particularly the coral reef system, and review the natural and anthropogenic factors that have influenced them. A brief section is devoted to the geologic history of the island, especially as it pertains to the evolution of the present-day land surface. A longer section discusses some of the significant historical changes resulting from human habitation and development, and how these changes have influenced the south shore reef tract. The final section introduces the coral reef itself, and provides a brief overview of preliminary findings.

Geologic History

Moloka'i is the fifth largest of the major Hawaiian Islands with an area of approximately 261 square miles. It's roughly rectangular shape results from the coalescence of two separate shield volcanoes: the 1.9 million year old West Moloka'i Volcano, and the younger (appx. 1.75 million year old) East Moloka'i Volcano (Figure 1). To the southwest is Penguin Bank, a submarine

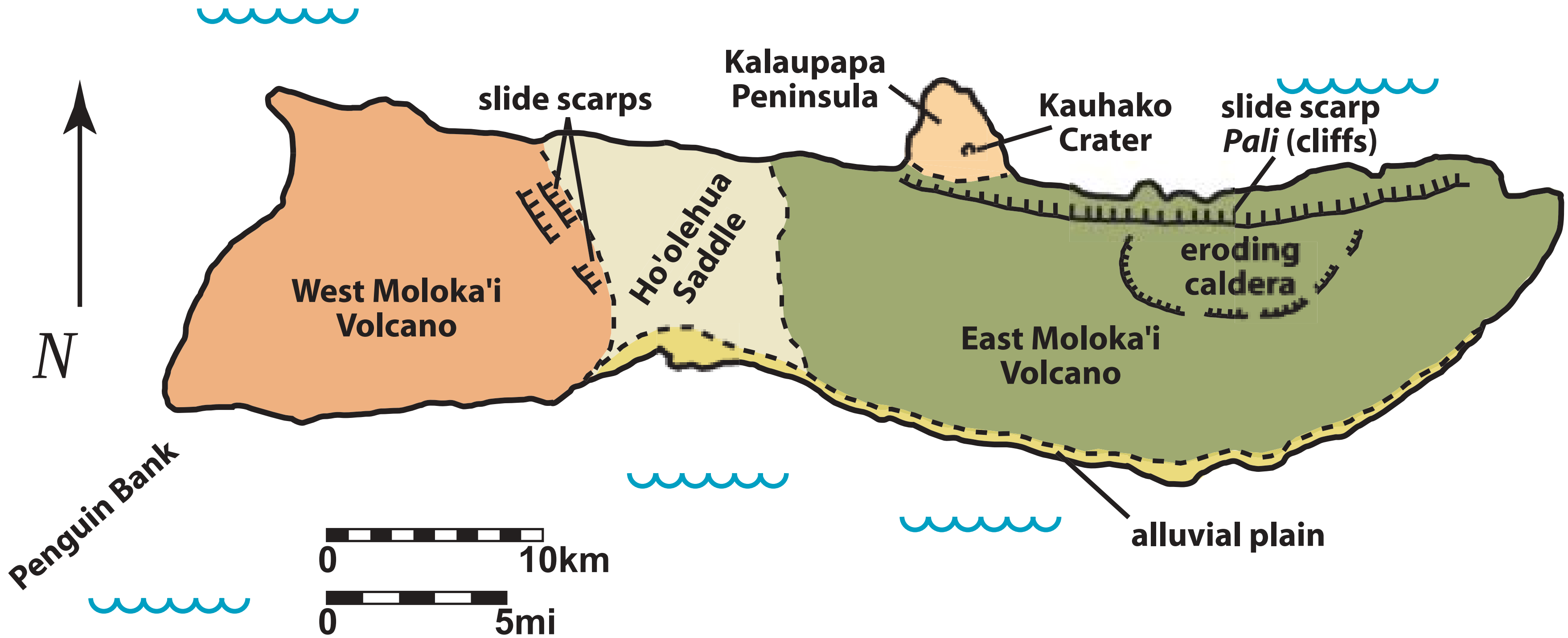


Figure 1. Generalized geology of Moloka'i. (modified from Hazlett and Hyndman, 1996)

platform lying at a depth of approximately 57 m (170 ft). It is suggested that Penguin Bank is either an offshore extension of the West Moloka'i rift zone, or a separate submerged shield volcano (Hazlett and Hyndman, 1996). Later in its life, the northeastern portion of the West Moloka'i Volcano collapsed into the ocean, leaving behind large slide scarps.

Lava from the younger East Moloka'i Volcano flowed across the lowland of the Ho'olehua Saddle and terminated against the flank and slide scarps of the West Moloka'i Volcano. Near the end of its active volcanism, the northern flank of the East Moloka'i Volcano slid into the ocean leaving behind the towering *pali* (cliffs) on the northeast coast of the island (Figure 2). The Kalaupapa Peninsula, on the north central coast of Moloka'i, resulted from more recent volcanic activity when the Kauhako Crater erupted approximately 300,000 years ago. The Kalaupapa Peninsula is backed by the towering *pali* on one side and storm-battered coasts on the remaining sides. Its inaccessibility led to its being chosen by the Kingdom of Hawai'i as a settlement for people afflicted with Hansen's Disease (leprosy).

Bisecting the island, the broad Ho'olehua Saddle, composed of eroded sediment of the East and West Moloka'i Volcanoes, forms a low-lying coastal plain along the south shore. The southeastern edge of the island is bordered by an alluvial plain constructed from a series of semi-contiguous alluvial fans associated with upland gulches. Three of the broader areas, formed at the base of the three major gulches of Kaunakakai, Kawela, and Kamalo

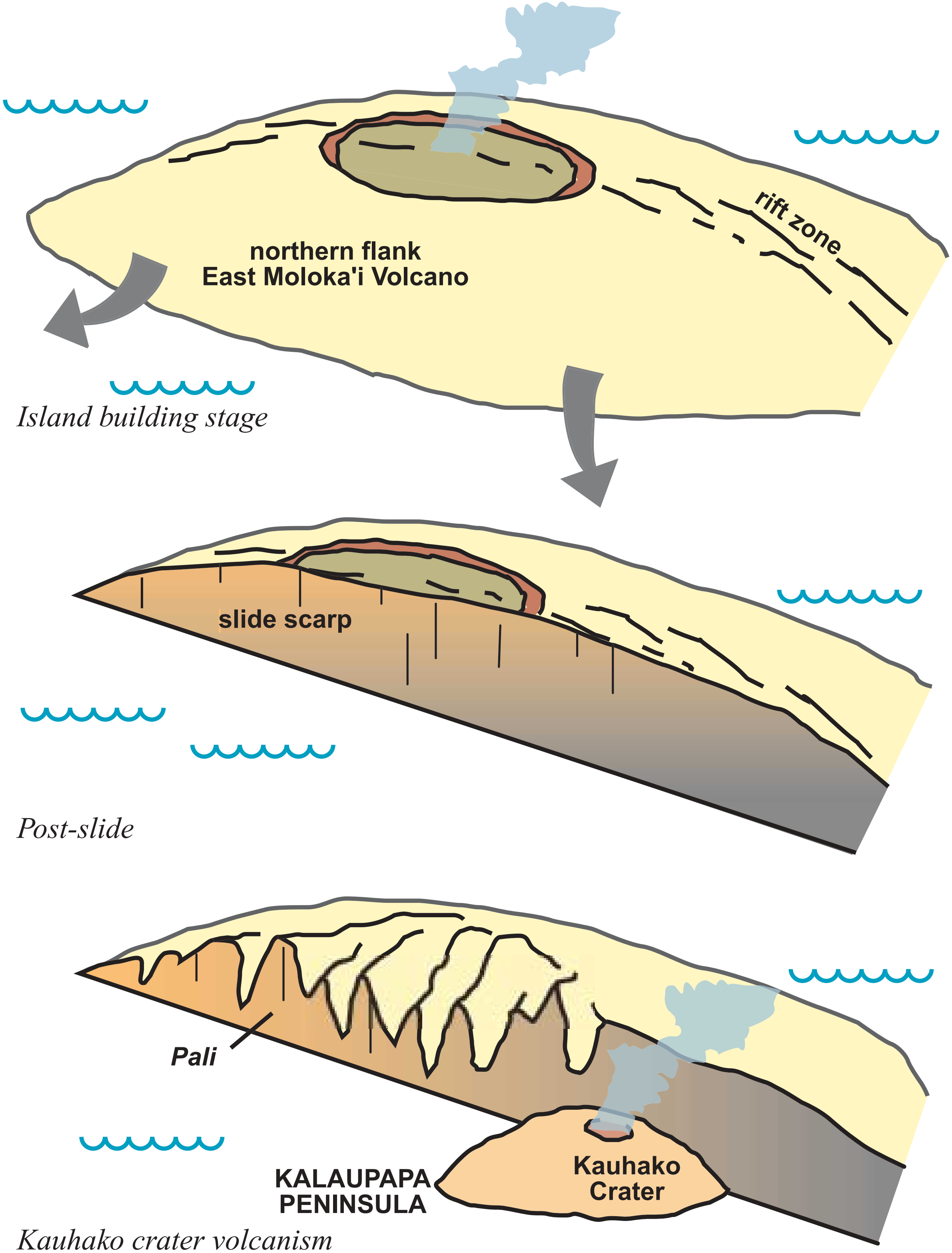


Figure 2. Diagram showing the steps in the formation of Moloka'i's steep *pali* (cliffs) and Kalaupapa Peninsula on the north shore (modified from Hazelman and Hyndman, 1996).

(*Kamalo'o)*, have played important roles in early human settlement of the southeast coastline. The deep loose soils, the presence of streams and springs, the low, irregular shoreline, and the relative protection and resources of the broad reef platform provided an inviting physical environment for early human occupation in the southeastern coastal area. Early Hawaiians took advantage of the natural system to develop a regime of coastal activities duplicated nowhere else in Hawai'i.

Human-induced Change

<u>600CE to 1000CE (Common Era)</u>

The early Hawaiians brought with them their customs and traditions, important among which was their system of land organization and use. In this feudal scheme, an *ali'i* (chief) would assign the use of a portion of the land to a small group or family unit. This family land, or *ahupua'a* (altar of pigs, named for the marker or stone found at its boundary), commonly comprised a valley, from the top of the watershed to the shore, and the adjacent reef and near-shore waters. The *ahupua'a* provided its inhabitants access to all they might need: water from a stream or localized springs, wood from the higher elevations, forage from the lower slopes, bottom land along the coast for taro, and access to the full resources of the adjacent reef. In return for the use of the resources, the people would provide a share of the production of the *ahupua'a* to the *ali'i.*

Land clearing and farming activities centered mainly on the growing of the traditional Polynesian staples, taro and sweet potatoes. However, botanists believe that the early Polynesians also introduced many other plants to serve their needs, such as sugar cane, bananas, coconut, breadfruit, ginger, pepper, and mulberry (Bryan, 1954). Early animal introductions appear to have been limited to a small domesticated pig, the dog, and the jungle fowl, with the Hawaiian rat possibly arriving as a stowaway (Bryan, 1954). Thus the combination of farming, fishing, and gathering provided for a community's needs.

There were no villages in this scheme, only occasional small residences (deLoach, 1975) and perhaps a community *hieau* (altar or sacred site). With few people and a broadly scattered population, adverse environmental impact was probably limited. However, there are those who feel that early clearing and burning, even on a small scale, caused accelerated erosion of the hinterland in South Moloka'i (pers. comm. E. Misaki, 2000).

<u>1000CE to 1400CE</u>

Perhaps most influential in the alteration of the coastal margin of south Moloka'i, were the more than fifty fishponds built on the inner edge of the reef flats. The fishponds are low stone walls, which partition off an area of the nearshore reef flat. One or two wooden-slatted sluice gates allow ocean water and small fish to enter. As the fish grow larger, they are unable to escape through the slats and are trapped within the fishpond where they are easily harvested. Both Hawaiian tradition and contemporary scholars place completion of the vast majority of the ponds in the early 1300's. These fishponds drastically modified the coastline and likely altered the transport patterns of materials, both down-slope and along-shore. For down-slope transport, they would form deep, relatively protected catchment basins. The prevailing winds and currents along the south coast move primarily east to west. The along-shore influence of each pond on material transport patterns varied with each pond's particular configuration, and its ability to interrupt or modify transport pathways.

1400CE to 1778CE

Located between the warring factions of Hawai'i, Maui, and Oahu, Moloka'i initially served as both a refuge from war and as a source of provisions prior to battles elsewhere (deLoach, 1975). Sometime prior to 1500CE, several of the coastal fishponds sustained considerable damage, though whether from warfare or storm surge is unknown. One story tells of Kapi'iohokalani, an *ali'i nui,* whose army invaded Moloka'i sometime around 1736CE, destroying sea walls and fishponds.

1778CE to 1900CE

In the early 1790s “Kamehameha I landed on this coast near Kawela with an invasion force of canoes that was said to stretch over 4 miles” (Pager, 1995; p. 125). It is said of his taking of Moloka’i that, “Kamehameha’s descent upon it had desolated the country” (Menzies, 1920; p. 118).

Also during this time, Westerners introduced livestock to the island, which drastically altered the land. The next hundred years saw the introduction of goats, horses, beef cattle, dairy cows, deer, sheep, and a breed of very large swine. By the mid-1800s, Kamehameha IV had a substantial herd of longhorn cattle being raised as trade goods on Moloka'i.

Not all animals were introduced for commercial purposes. In 1870, the Duke of Edinburgh arranged for a small herd of deer to be transported from Japan as a gift to Kamehameha V, who promptly had them transported to Moloka’i. Here they were allowed free range under a royal *kapu* (prohibition) and thus flourished (Judd, 1936). The deer, joined by feral goats and swine, today continue to thrive, particularly in the less accessible areas of the eastern half of the island, where grazing of grasses and low ground cover has lead to significant deforestation and rooting of the pigs has increased erosion of the upland soils.

The native vegetation of Moloka’i was ill prepared for the invasion of grazing animals. There were no naturally occurring terrestrial mammals in

Hawai’i, (Bryan, 1954) and the flora evolved without defenses against grazers-- soft bark, tender greenery, no thorns. As the numbers of animals grew and their range expanded, Moloka’i’s native vegetation was affected and the environment began to change. The overstocking of the lands removed the natural covering of grass, and subsequent storms led to increased soil erosion (Cooke, 1949). The southern watersheds were marginally dry to begin with, so without vegetative cover to hold the soils on the upper slopes, erosion rates accelerated. As the topsoil washed downslope, recovery of any remaining vegetation became more problematic. The eroded soil was washed to the south side of the island and was deposited in the fishponds and the shallows between the shore and the reef (Cooke, 1949).

In the mid-1800s cattle ranching was the primary activity in a large part of the upper reaches of the eastern Ho'olehua Saddle and the western portion of the eastern volcano. When ready for market, the cattle were driven south to Pala’au for shipment. The trampling of driven herds increased the loss of grasses and other vegetation cover from grazing. Although Moloka'i has been experiencing a draught situation in recent years, possibly lessening the flow of sediment to the coast, after a heavy rain, a red sediment plume spreading over the reef from Pala’au is visible for miles (pers. comm. Bill Puleloa, 2000).

The end of the nineteenth century found Moloka’i with very few people, many feral animals, and large, once-forested areas denuded. Much of the water-retaining native flora that once covered the upper areas of the south-draining watersheds was gone. Even the small areas of precious sandalwood had been stripped barren.

<u>1900CE to present</u>

The twentieth century brought a complex mix of human activity that influenced erosion and coastal change on Moloka'i. Significant events during this period include:

- Between 1898 and 1905 Moloka'i Ranch, by far the largest landholder on the island, shifted from open country grazing to a paddock system. The use of paddocks to control grazing patterns limits the impact of a herd on the vegetation in any one given area. Also, a major effort was made to reduce the number of wild goats and deer (Henke, 1929).
- In 1902 the red mangrove (*Rhizophora mangle)* was introduced by the American Sugar Company in an effort to stabilize the coastal mudflats (Kepler and Kepler, 1991). In a 1917 letter, George Cooke of Moloka'i Ranch wrote that the purpose of the introduction of the mangrove was to hold back "soil washed down by every heavy rain into the sea" (Allen, 1998). Considering the information provided by Cooke and what can be observed in Pala'au today, it is likely that this introduction of mangroves was *specifically* directed at solving the sedimentation problems encountered at Pala'au.
- By 1907, the sheep population on Moloka'i reached 17,000 animals, grazing mostly on the grasses of the Ho'olehua Saddle. Sheep tend to graze

closely, denuding large areas of pasture. Eventually the ranchers realized that cattle were more profitable than sheep, but not before denuding the upper pastures of the Saddle. Sheep raising was finally discontinued “only because of reduced grazing areas and a poor wool market” (Henke, 1929).

- In 1912 the Moloka’i Forest Reserve was created, covering a large part of the eastern half of the island as a cooperative effort of government and local landowners. Fencing and voluntary restraint were used in attempts to give the upland slopes of the south-draining watersheds a chance to recover from the livestock damage.
- In the 1920s, much of the Ho’olehua Saddle area was set aside as Hawaiian Homestead lands. Clearing the land for farming served to make the loose red soil more susceptible to the erosive effect of the prevailing winds. The subsequent planting of windbreaks was only marginally successful in mitigating the damage. Ironically, the homesteaders found it more beneficial to lease their homesteads to the big pineapple producers than to farm them individually, leading to the environmental problems often associated with extensive monoculture such as susceptibility to disease and insect infestations (Keesing, 1936).
- Between 1928 and 1934, the modern wharf and mole (stone causeway) were built at Kaunakakai. Dredging of the entrance channel and main harbor was completed in 1934. Since then, the area has been dredged

at least seven different times for maintenance purposes (U.S. Army Corps of Engineers, 1978).

- By 1930, much of Moloka'i was devoted either to pineapple cultivation or to grazing. A majority of the fishponds had been abandoned, likely in part because of lack of the manpower needed to keep the walls in good repair and keep the ponds cleared of sediment.
- In 1948 the Moloka’i-Lana’i Soil Conservation District was formed by the US Department of Agriculture to assist local residents in reversing environmental damage and improving the management of their lands. A field office was established on Moloka’i from which information and assistance could be disseminated to landowners, farmers, and tenants to promote their conservation efforts by a broad variety of means such as soak or drip-irrigation and other counter-erosion techniques (pers. comm. S. Cox, 2000).
- Development along the south shore in recent times has been mainly small-scale residential, including low-rise condominiums and private homes. The county sewage treatment system covers only the town of Kaunakakai. Newer residences outside the town have septic systems, while the older ones have cesspools. It is possible that seepage into the water table from these systems flows out onto the reef platform and enhances the nutrification of the brackish and marine flora, causing “blooms” of undesirable algae and cyanobacteria near population centers (pers. comm. J. Souza, 2000).

Moloka'i's Coral Reef System

The fringing coral reef tract along Moloka'i's south shore consists of three distinct parts: 1) inner reef flat; 2) reef crest; and, 3) outer fore reef (Figure 3). Sedimentation and natural processes vary significantly between these environments. The inner reef flat, lying in shallow water nearest the shoreline, is a relatively level, broad platform and the first to be influenced by terrestrial sedimentation and runoff. The reef crest is the zone where waves impinge and commonly break. Water depth is extremely shallow over the reef crest (less than 1 m), and it is occasionally exposed during very low tides. The outer fore reef slopes seaward from the reef crest to depths of about 35 m (105 ft), and corals grow abundantly to depths of about 25 m (83 ft). From a depth of 14 m (45 ft) to 25 m (83 ft), the Moloka'i reef has a typical spur-and-groove morphology. Reef spurs (buttresses) are oriented shore-perpendicular and are separated by broad grooves (channels) which transport sand offshore. Live coral grows on the spurs, and commonly in the grooves as well; relief is on the order of 1 to 3 m (3.5 to 10 ft).

Wave energy (Figure 4) plays an important part in the morphology and conditions of the fringing reef. The island of Lana'i shelters Moloka'i from most of the wave energy arriving from the south. However, waves from the North Pacific swell refract and wrap around the east and west ends of the island, causing the reef to pinch out approximately 5 km (3 mi) from each end

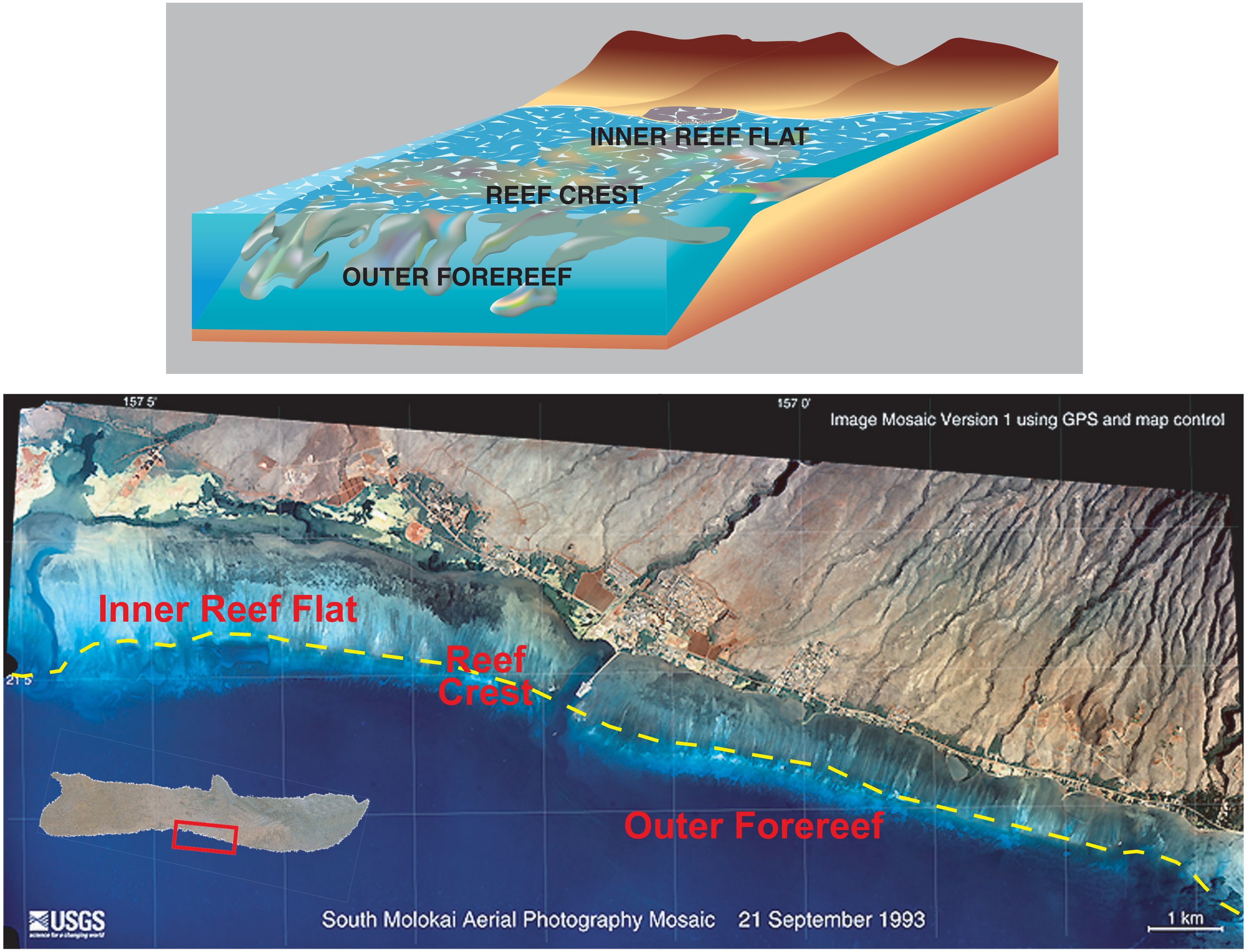


Figure 3. Schematic diagram (top) of typical fringing reef tract. Aerial photograph (below) showing the approximate locations of the inner reef flat, reef crest, and outer forereef on Moloka'i.

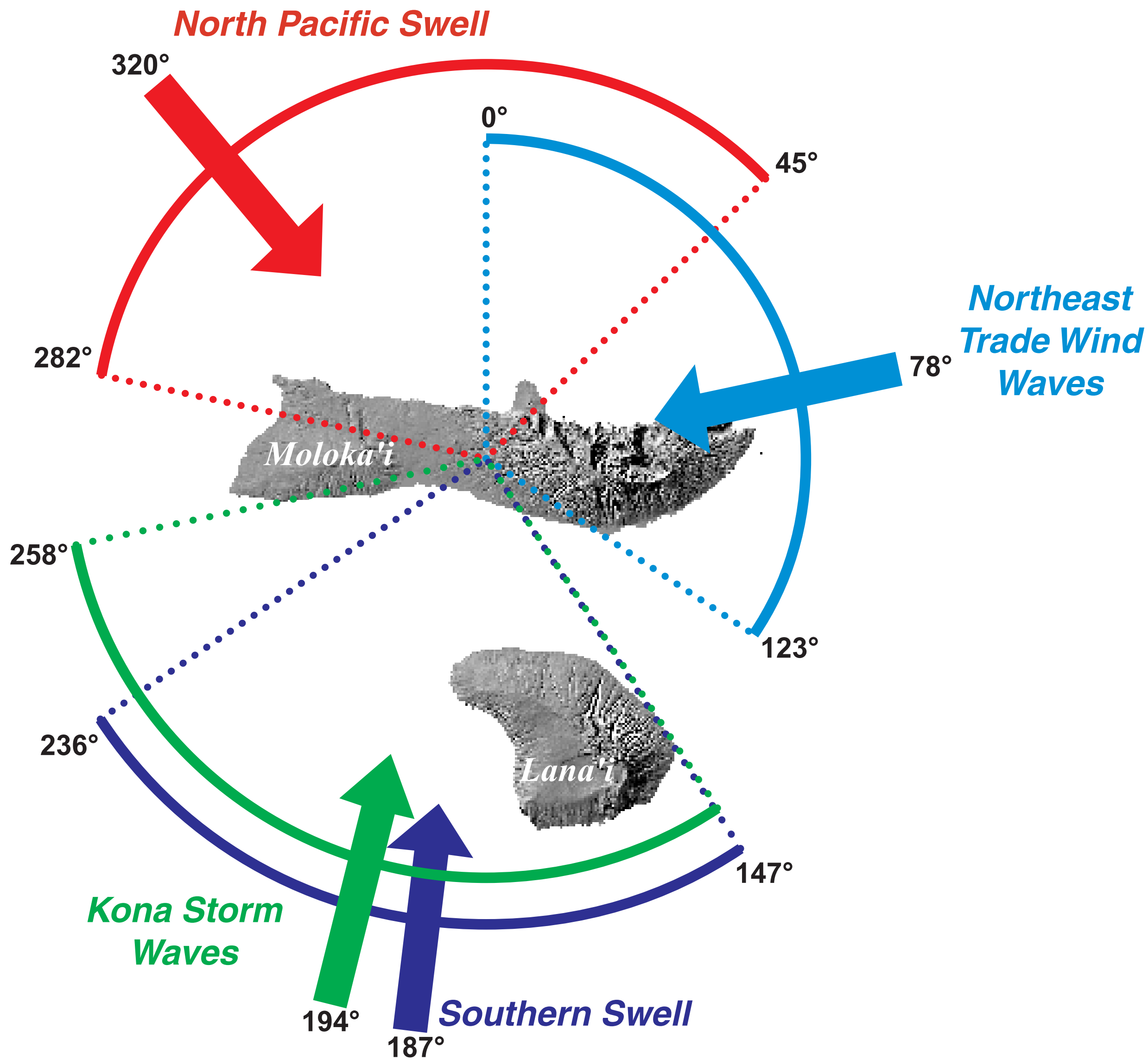


Figure 4. Moloka'i wave energy regime (modified from Moberly and Chamberlain, 1964; Moberly et al, 1965)

of the island. The northeast trade winds generate short, steep waves, and play a large part in the resuspension of sediment on the reef flat.

Initial observations (Jokiel and Brown, 2000, unpublished) show that coral coverage at the 10 meter depth contour on the outer fore reef is extremely high (>90%) from Kaunakakai westward to Hale-O-Lono (Figure 5). This area shows high diversity of corals, including *Porites compressa*, and *Montipora spp.*, shifting to *Porites lobata* (a more wave-resistant species). From Kaunakakai eastward to One Ali'i the coverage of live coral on the fore reef is less than 10%. From One Ali'i to Kamalo, the coral coverage again is extremely high (>95%) and is dominated by *Porites compressa*.

Summary

Today the south shore is still edged with fishponds, some of which are partly filled with sediment and some of which are overgrown by mangroves. High amounts of algae are found growing on the inner reef flat for large stretches east of Kaunakakai, possibly due to high nutrient levels in the water. At times, especially during periods of high tides combined with strong trade winds, the water flowing over the inner reef platform is brown with suspended sediments. For the last decade of the twentieth century, draught conditions on Moloka'i have possibly lessened the amount of sediment added to the waters of the platform. However, during heavy rains, rivers flow brown and

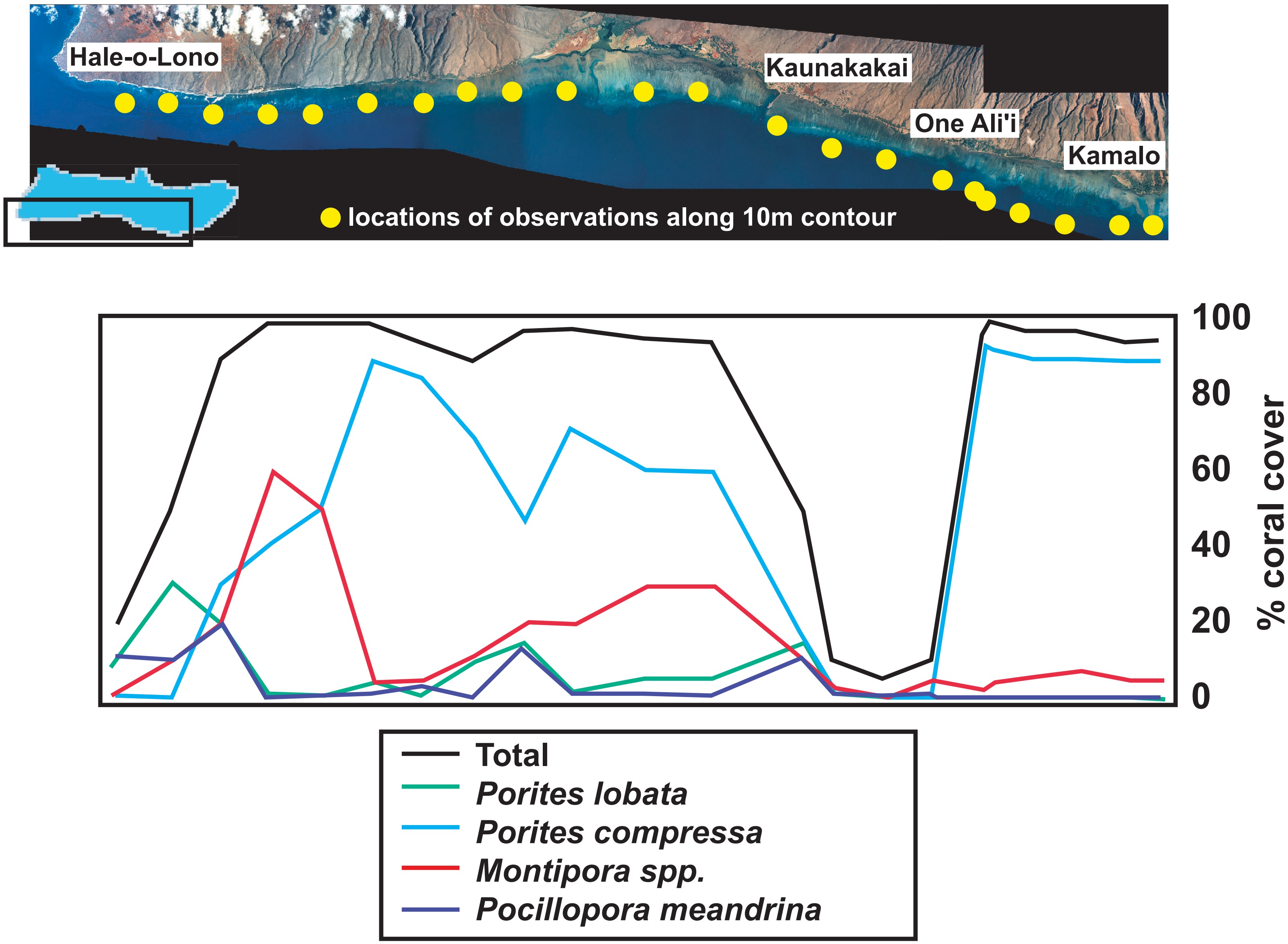


Figure 5. South Moloka'i coral cover at the 10 meter contour. (Jokiel and Brown, 2000, unpublished)

large quantities of sediment are added to the offshore water. Much of the sediment deposited on the inner reef platform from the eastern end of the island is carried westward by currents. There are few living corals on the inner reef platform from Kaunakakai to One Ali'i, possibly due to large amounts of sediment. The outer fore reef in this area generally contains less than five percent live coral along the 10 m (33 ft) isobath, and is mostly covered by old reef deposits, sand, algae and rubble.

FIELDTRIP STOPS

General Information

The following section is a listing of fieldtrip stops in sequential order from west to east (see fieldtrip map for locations of stops, Figure 6).

Individual fieldtrips may vary in number or order of stops visited, depending on scheduling. Fieldtrip stops 1 through 21 are “dry” stops, easily accessible by car; some include short walks. Driving directions given in italics in the stop descriptions are with respect to the mileage markers along the highways. Fieldtrip stops A through F are offshore and only accessible with a boat. Local charters are available from the Kaunakakai Wharf. General latitude and longitude (WGS84 datum) for these locations are given in italics in the stop descriptions.

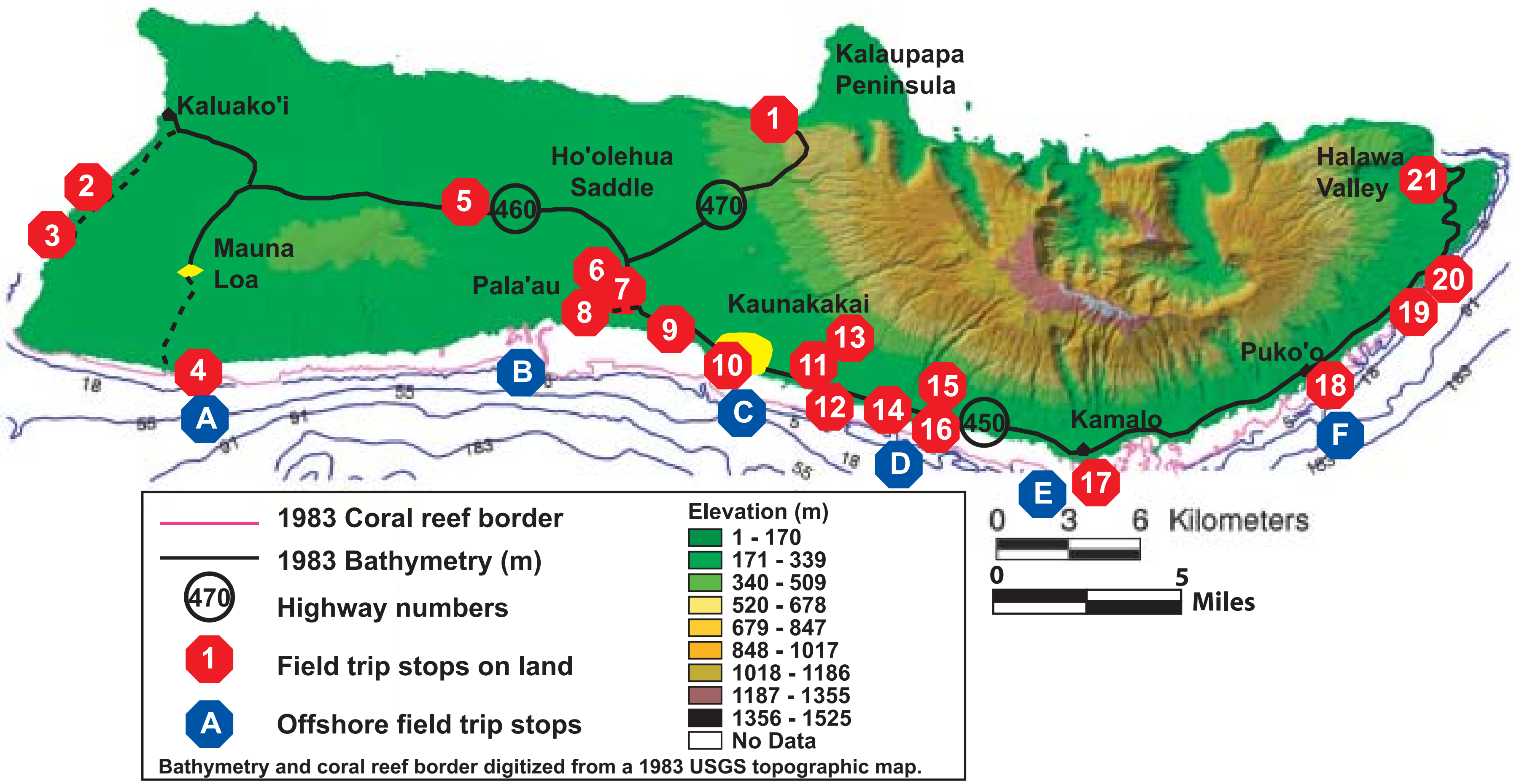


Figure 6. Map of field trip stop locations. See text for description of stops.

Dry Land Fieldtrip Stops

<u>Stop 1</u>: <u>Kalaupapa Overlook</u> – *Drive north to the end of Highway 470 and park in the spaces provided. Follow the path for a short distance, through a forest of ironwood trees, to the overlook.*

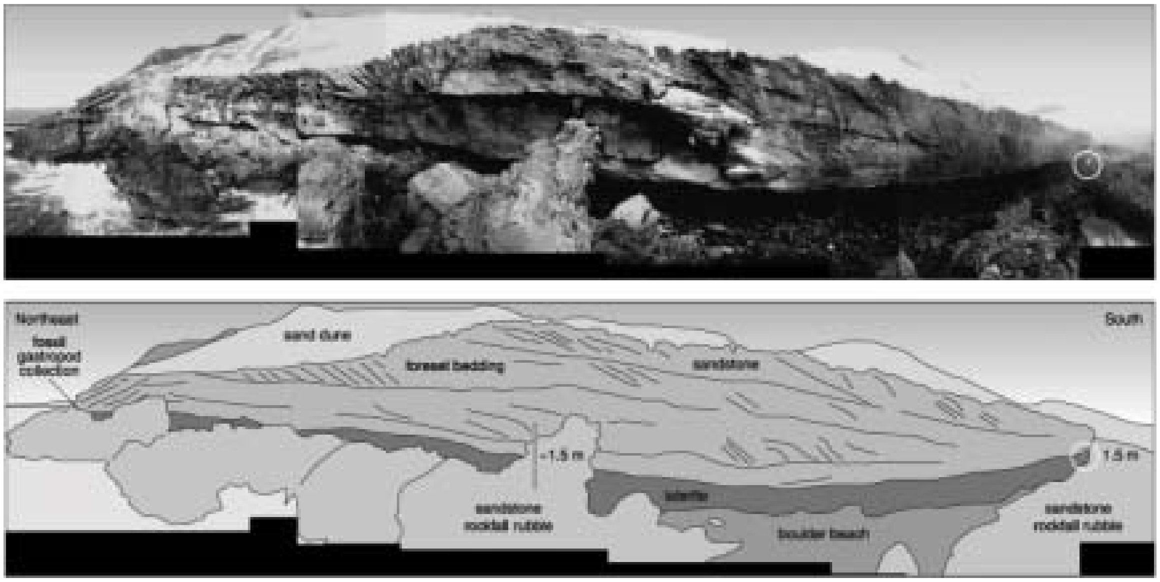
View from Kalaupapa overlook *(S. Cochran)*

This stop provides a scenic view of some of the most spectacular geomorphic features of Moloka'i. The steep *pali* (cliffs) were formed when a large portion of Moloka'i's eastern volcano broke off approximately 1.4 million years ago (Clague et al, 1990) in a catastrophic landslide, known as the Wailau Slide. The Kalaupapa Peninsula is a small shield volcano, which post-dates the landslide and was formed by the eruption of the Kauhako Crater approximately 300,000 years ago. In 1865, King Kamehameha V signed an order declaring the triangular-shaped Peninsula as a colony for persons afflicted with Hansen's disease (leprosy). With water on two sides, and the 1700 ft pali on the third, the inhabitants were effectively isolated.

<u>Stop 2: Papohaku Beach</u> – *Go west on Highway 460 for 15 miles and turn right on Kaluako'i Road. Go 5.5 miles on Kaluako'i Road, past the entrances to the Kaluako'i resort and Ke Nani Kai condominiums, turn right into the parking lot for Papohaku Beach Park. Watch for thorns from kiawe trees underfoot when walking the short distance over the dunes to the beach (don't take your shoes off until you are on unvegetated sand).*

This high-energy beach contains the largest body of calcareous sand in Hawai'i. There is no fringing reef on the west end of Moloka'i to protect the beach or supply the sand locally, except for a few coral and algal veneers offshore to the north and south of the beach, therefore it is suggested that the trade winds blow sand in from the Mo'omomi Dunes (Hazlett and Hyndman, 1996). Here one can visibly watch the process of aerial transport as the winds form and move ripples along the beach. A shelf of modern beachrock is usually exposed along the edge of the water at low tide.

<u>Stop 3: Pu'u Koai</u> – *Continue down Kaluako'i Road 1 mile past Papohaku Beach Park (see Stop 2, above, for directions) until the road dead ends. Turn right and go 0.4 mile, then turn right again and go 0.4 mile (follow the main road as it bends to the left) to a short coastal access road on the right. Park* *at the end of the short access road and hike a short distance over the rocky shoreface northward.*



Photomosaic and interpretation of outcrop at Pu'u Koai. Person (circled) standing in middle right of photo for scale. *(K. Evans)*

This outcrop on the western end of Moloka'i shows prominent sets and high-angle foreset beds of a fossil sand dune. This eolianite exposure is related to the Mo'omomi dune system on the northern coast of West Moloka'i. The medium- to fine-grained sandstone is mostly calcareous. The contact with the underlying laterite is sharp, nearly planar across the outcrop, and at 3.8 m (12.5 ft) elevation. Root casts are common in the sandstone, and some high-spired land snails are found in the lowermost set.

Rounded boulders and cobbles mantle much of the southwest Moloka'i coast. Some may be derived from chemical weathering of the lateritic parent rock, others by physical abrasion in the pounding surf. At this locality, however, waves are undercutting the sandstone outcrop, eroding the underlying, less resistant laterite.

Some key questions about these strata are: 1) are sand dune fields an episodic phenomena on Moloka'i?; 2) and if so, can we relate episodes of dune migration to climate change?; 3) what is the relationship of these fossil dunes to rocks at nearly the same elevation in and around Kaunakakai?; 4) what is the rate of coastline retreat?; and, 5) is this retreat a local phenomenon? For additional information about eolianite exposures on the western end of Moloka'i see Hearty (1999) and Fletcher et al (1999).

Stop 4: Hale-O-Lono – *Follow Highway 460 west for 17 miles to the town of Mauna Loa. Take the first right on Mokio Street. After a few blocks you will enter into Moloka'i Ranch property and the road will change from paved to unpaved dirt. Follow the dirt road for approximately 5.5 miles to the water's edge.*

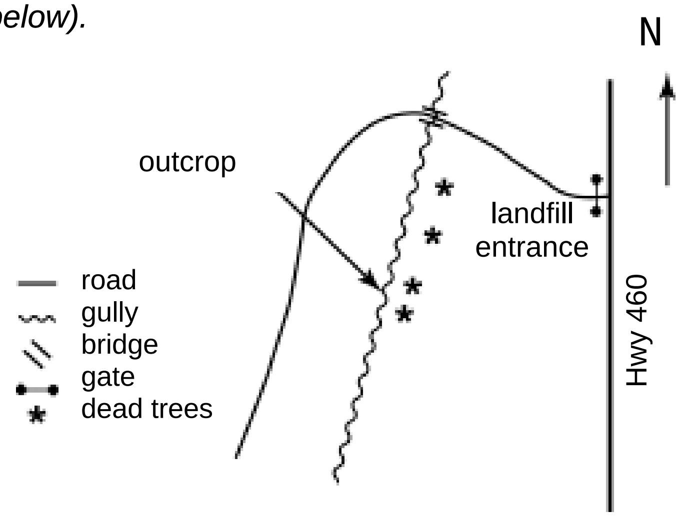
Once a bustling harbor, this stop marks the approximate location where the southern shore's fringing reef pinches out as it nears the west end of Moloka'i. No longer sheltered by the shadow from Lana'i, the south swell and diffracted waves from the north Pacific swell break along this portion of the coast. The Hale-O-Lono area appears to represent a zone where wave energy is of sufficient strength to prevent extensive reef development. Just east along the coast, modern beachrock crops out near the water's edge.

Stop 5: **Highway 460 Ho'olehua Saddle** – *mile 9.5*

Hauakea pali *(C. Storlazzi)*

The steep hillside slopes of Hauakea on the western side of the Ho'olehua Saddle are remnant scarps formed when the northeast side of Moloka'i's West Volcano slid into the sea. The saddle was formed when lava flows from Moloka'i's East Volcano piled-up against the flanks of the West Volcano. There are round residual stones in the deeply weathered, laterite soils of the Saddle. These soils are easily eroded, as evidenced by the deep gullies cutting through the landscape, and are transported downstream to the Pala'au area of the coast.

Stop 6: Tsunami Deposits – *Park at the entrance to the Landfill at mile 2.9 on Highway 460. The outcrop is visible along the eastern edge of the gully (see drawing below).*



Tsunami deposits on Moloka'i *(S. Cochran)*

Much of the area surrounding Kaunakakai is built upon tsunami deposits, possibly from the ancient tsunami generated by the collapse of the west coast of the Big Island of Hawai'i 100,000 years ago (Hazlett and Hyndman, 1996; Moore, 2000). Described as a coral-basalt breccia-conglomerate by Moore et al (1994), these rocks units crop out 30 to 70 m above present-day sea level, and contain sub-rounded to angular basalt clasts and light-colored fragments of reef material.

Stop 7: Highway 460 West End Overlook – *mile 2.8*

This stop alongside the Highway provides an overview of the reef flat along the west end of Moloka'i. In the afternoons, after the trade winds have been blowing, a red sediment plume can be seen bordering the shoreline.

Stop 8: Pala'au Mudflats – *From Highway 460, turn seaward on Pala'au Road, approximately 2.3 miles west of Kaunakakai, at the corner where Hawaiian Research Ltd. is located. Follow the unpaved road approximately 2.5 miles, just past the Moloka'i Sea Farms. Park near the gate to Moloka'i Ranch and walk in along the unpaved road.*

Pala'au muds held back by mangrove system at water's edge *(C. Storlazzi)*

A 30-40 minute walk west onto Moloka'i Ranch property from the gates near the Moloka'i Sea Farms brings one to a vast area of mud trapped behind a mangrove barrier. In 1902, the American Sugar Company introduced the Florida red mangrove, *Rhizophora mangle*, to the area in an attempt to stabilize the coastal muds and keep them from washing into the sea. The introduced mangrove has flourished, building out the shoreline, especially here in the Pala’au area. It has also propagated along the south coast, sometimes even growing on and in fishponds. With permission from the management at Moloka'i Sea Farms, the mangroves can also been seen from the *makai* (ocean) side by taking an access path they have cut through the mangrove barrier near the end of their stock ponds.

<u>Stop 9: Kamehameha V Coconut Grove</u> – *Highway 460, mile marker 1*

King Kamehameha V historical Coconut Grove with freshwater springs at water’s edge *(S. Cochran)*

One thousand trees were planted on these ten acres in the 1860’s in honor of King Kamehameha V. Originally five freshwater springs could be found in the grove, each one purposely set aside for either drinking, communal bathing, farm use, or as the "kitchen sink spring” (Anderson et al,1973; p. 90). Tidal inundation and recent erosion has created a beach scarp up to 1 m high along the beach.

<u>Stop 10: Kaunakakai Wharf</u> – *mile 0*

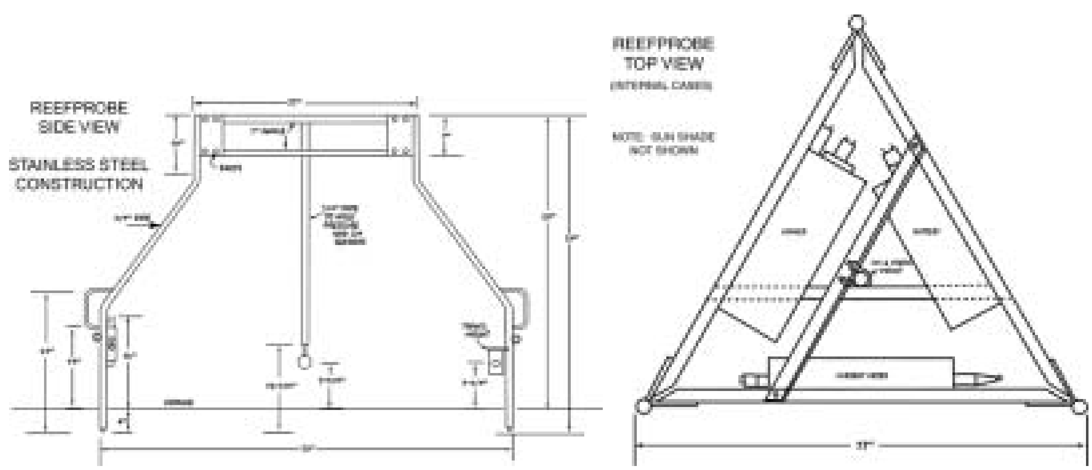
Aerial view of Kaunakakai Wharf *(M. Field)*

The Kaunakakai Wharf, solid-fill causeway (mole), and dredged channel were built in the early 1900's and immediately caused changes to the local hydrodynamic regime. Local residents attribute much of the muddy waters on the inner reef flat to the fact that currents can no longer flush out the system. Recent modeling studies by the U.S. Army Corps of Engineers (Bottin and Acuff, 2001) show that replacing the most shoreward 183 m (600 ft) of the solid-fill causeway with a pile-supported bridge, and restoring the shoreline to a more natural state, will result in improved current patterns, allowing sediment to continue to flow in a westerly direction.

<u>Stop 11: Highway 450 Roadcut</u> – *mile 1.1*

On the *mauka* (inland) side of the highway, is a roadcut exposing ancient carbonates overlying basalt. The grainstones show poorly developed stratification. Comparable deposits are exposed near the church buildings across from the King Kamehameha V Coconut Grove (one mile west of Kaunakakai), at about the same elevation. These deposits may be indicators of a sea-level highstand between 4 and 1.5ka (B. Richmond, pers comm.)

<u>Stop 12: Kamiloloa Reef Flat</u> – *Highway 450, mile 1.8, accessible via the Hotel Moloka'i*



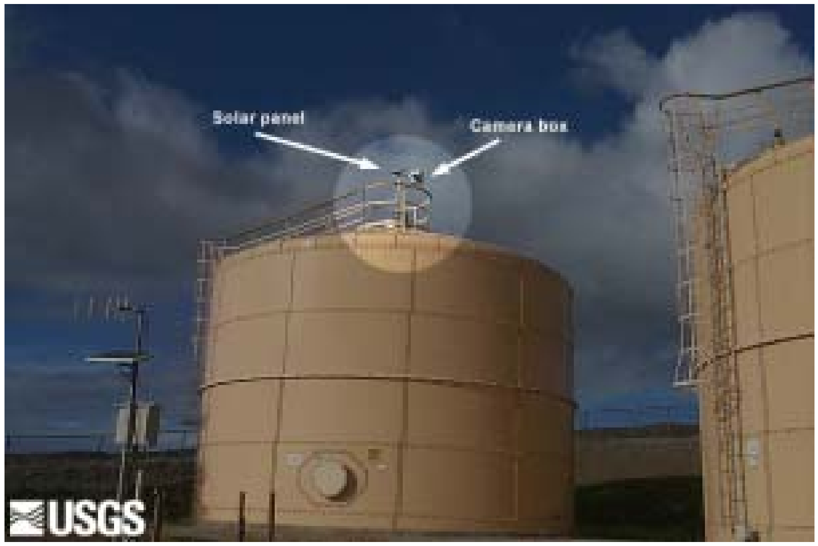
Schematic diagram of REEFPROBE

Approximately 400 m offshore from the beach at the Hotel Moloka'i, on the shallow reef flat, is a USGS instrument package designed to measure current velocity and direction, pressure, salinity, and suspended sediment. The tripod legs rest on hard substratum and are secured with anchor bolts into the reef rock. The instruments are attached to the REEFPROBE legs and are continually submerged. The battery and data logger are mounted sub-aerially in the rack above. Data are downloaded quarterly (turnaround time is determined by battery life). Initial results show significant dampening of signals through time due to biological fouling, therefore the instruments must be cleaned on a regular weekly basis.

A few meters to the southwest of the REEFPROBE, in 1 m of water, is a pair of sediment trap tubes. Each sediment trap consists of a PVC tube with honeycomb baffle at the top. Initially deployed in February 2000, the traps are monitored quarterly at the same time as the REEFPROBE. Like the instrumentation package, the traps tend to undergo high rates of biological fouling due to the shallow water and high light levels.

A few meters to the southeast of the REEFPROBE is a CRAMP (Coral Reef Assessment and Monitoring Program) photoquadrat site in 1 m of water. Baseline photographs were taken in February 2000. The site is revisited annually to document change on a colony level.

Stop 13: Kamiloloa Digital Camera Station – *Highway 450, mile 1.8, uphill on the road directly across from Hotel Moloka'i (Stop 12).*



Digital camera mounted on Maui County water tank at Kamiloloa (*S. Sides*)

This is one of two on-land digital camera stations established by the USGS to track and monitor suspended sediment events on the Moloka'i reef flat. The second camera station is located atop a water tank in the Kawela Plantation II subdivision a couple of miles to the east. Initially deployed in December 2000, the solar-powered camera systems capture four high-resolution digital images every day at each site. For more information, visit http://TerraWeb.wr.usgs.gov/projects/Molokai/digital_camera/ on the world wide web.

Stop 14: Kawela Fan Delta – *Just before mile marker 5 on Highway 450, pull into the vacant lot that has a couple of arched framework wooden structures.*

The delta is located a few hundred meters to the east along the beach. Alternatively, park on the highway next to the Kawela Bridge and walk along pathways following Kawela Gulch to the beach to access the delta.

Prograding fan delta at mouth of Kawela Gulch *(K. Evans)*

This location is a prograding fan delta composed of sediment carried down from Kawela Gulch. Fan deltas similar to this can be seen all along the southeast coast of Moloka'i. The coastal plain is composed of interfingering terrigenous fan deltas, and carbonate beach and reef deposits.

Stop 15: Kawela Plantation East End Overlook – *At mile 5.1 on Highway 450, turn inland into the Kawela Plantation I subdivision. Follow the main drive as it winds its way uphill to the back of the neighborhood.*

This stop provides a panoramic overview of the reef flat along the east end of Moloka'i. If the sun angle allows, you can see numerous “blue holes” embedded within the reef flat. See Stop 17 for a further description of blue holes.

Stop 16: Kakahaia Beach Park – *Highway 450, mile 5.6*

Cut-back erosion at Kakahaia Beach Park *(K. Evans)*

Recent erosion has produced a scarp in the back beach at the edge of the park grass, exposing a layer of laterite soils over a gray-black layer that contains bits of carbonized wood. Anthropogenic beach debris found between the horizons indicates that the area has probably been filled and subsequently eroded.

<u>Stop 17: Kamalo Harbor</u> - *Highway 450, mile 10.1 where the highway makes a sharp bend inland; turn into the dirt access road and park near the water's edge*

Deep gulches of Kamalo as seen from shore *(S. Cochran)*

Kamalo Wharf and Harbor are thought to be built before the 1860's, and were once a major facility on the island, but are now only used by local residents. The alluvial plain around Kamalo is the largest on Moloka'i, and is comprised of upland sediments supplied from the Kamalo Gulch. Offshore, this area sustains a large area of fairly healthy *Porites compressa* (finger coral*).*

Aerial view of Kamalo Wharf and Blue Holes

On the reef flat to the east are a number of "blue holes". Studies are ongoing to determine whether these blue holes are erosional features in an otherwise widespread expanse of healthy reef, remnants of paleo sand channels that have been overgrown, or karst features formed during sea-level lowstands and modified by subsequent reef growth.

Stop 18: Puko'o Harbor – *Highway 450, mile 15.7 – 15.8, there are public access roads both on the north and south sides of the Harbor*

Puko'o has had a somewhat controversial history concerning access rights for native Hawaiians. This was originally the main town on Moloka'i, housing many government buildings, including the Post Office. Reference is made to a government road being built in 1904 to serve the then-existing

Puko'o Pier, which was subsequently demolished in the 1920's (DeLeon, 1990). There is no pier visible today.

Once owned by Canadian-Hawaiian developers, the 33-acre property surrounding the original Puko'o Fishpond was first zoned for a small resort. Dredging operations in 1973 created navigable waters in the tri-lobed harbor and led to local attempts to secure public right-of-way access (Glauberman, 1983). The property was purchased by the Maud Van Cortland Hill Schroll Trust in 1979-1980, who then had the zoning "downsized" to rural use. This downsizing led to a requirement for beach access. Reference is made to an in-progress east-side pedestrian way into Puko'o lagoon (DeLeon, 1990). Since that time, a 5.5-acre parcel was turned over to a community land trust to maintain the land and adjoining lagoon for community use. (Tanji, 1999).

The waters near Puko'o are home to an endemic species of large finger coral, *Porites pukoensis*. This rare blue form was first described from a specimen found at this location. The State of Hawai'i Department of Land and Natural Resources (DLNR) has proposed that this coral be submitted as a candidate for the Endangered Species List due to its limited Hawaiian range (Wilkinson, 2000).

Stop 19: 20 Mile/Murphy's Beach – *Highway 450, mile marker 20*

The modern fringing reef nears the shoreline here as it begins to pinch out on the eastern end of Moloka'i. This is an excellent snorkel spot, although it is best at high tide. During low tide the waters are so shallow that it is sometimes difficult to navigate your swim through the reef.

Directly around the corner to the west from the point at Murphy's Beach, is a small bay. The reef curves into the bay and is characterized by vertical walls. Snorkelers can enter the water from the rocks on the point, or by swimming around the point from Murphy's Beach when conditions warrant. When the tides are too low at Murphy's Beach, this is an excellent alternative snorkel.

Stop 20: Pohakuloa and Kanaha Points – *Highway 450, mile 21.4*

Wave-cut terraces on Moloka'i's east end *(S. Cochran)*

To the east of Murphy's Beach, several wave-cut terraces line the coast between the highway and the water.

<u>Stop 21: Halawa Valley Overlook</u> – *Highway 450, mile 25.9, follow the highway as it turns inland and goes up and over the east end of the island. The overlook is a pull-off after a series of hairpin turns.*

This scenic valley warrants a stop if time permits. It was once the site of large taro farms, until a tsunami destroyed the area in 1957. The walls of the terraced fields still remain. On a clear day, two waterfalls can be seen at the head of the Valley. To the left (south) are the 250 foot tall Moa'ula Falls. On the right (north) are 500 foot tall Hipuapua Falls.

Offshore Fieldtrip Stops

<u>Stop A: Hale-O-Lono</u> – *21.0803 degrees N, 157.2462 degrees W*

This site is where the southern shore's fringing reef pinches out as it nears the west end of Moloka'i. No longer sheltered by the shadow from neighboring islands, swell from the south and diffracted waves from the north break along this portion of the island. In an effort to characterize the wave energy regime and how it affects the fringing reef, a wave gauge (pressure sensor) with a battery-operated data logger was deployed at a water depth of 10 m (33 ft) in February 2001. Data are downloaded from the logger quarterly (turnaround time is determined by battery life). Initial results from wave gauges stationed along the south shore of Moloka'i show that they are capable of detecting wave events that can be directly correlated to sediment resuspension events recorded from sediment traps and cameras. A sediment trap tube was attached to the wave gauge in April 2001 and is monitored quarterly at the same time as the wave gauge. See Stop 12 for a description of sediment trap tubes.

Stop B: Pala’au Fish House Channel – *21.0871 degrees N, 157.1085 degrees W*

Although accessible by foot via the path cut through the mangroves from the Moloka'i Sea Farms, this area is easier to access by boat. The reef flat near the inner channel and around the Fish House is sometimes fully exposed at low tide and can be easily walked. Fine sediment covers most of the reef flat, and algae can be found growing on the few areas of exposed hard bottom. There is no live coral on this portion of the reef flat.

A snorkel through the mid Pala’au Channel area takes one through a transition zone where small colonies of partially-live and healthy coral are found. There is debate as to whether these corals are remnants of a once-thriving area of healthy reef that is slowly dying, or are newly attempting to re-colonize an area. As one moves seaward, more and more live healthy corals can be found. This transition zone in the Pala’au Channel was chosen as a Coral Reef Assessment and Monitoring Program (CRAMP) site. A photoquadrat area has been staked out along the side of the channel in 1 m (3 ft) of water, spanning this transition zone, in order to monitor the line of healthy coral.

The outer Pala'au area was chosen as a site for CRAMP monitoring because it was hypothesized that it would represent the "unhealthy" endmember for Moloka'i's coral reef due to along-shore currents depositing sediment in the curve of the coastline. CRAMP monitoring transects are spaced at 3 m (10.5 ft) and 10 m (33 ft) depths. Both biological transect and photoquadrat CRAMP baseline data were collected in February 2000, and these locations are revisited annually to detect change. Initial results show that there is a healthy, diverse reef in this area. For more information about CRAMP methodology and techniques visit http://cramp.wcc.hawaii.edu/ on the world wide web.

Additional instruments at Pala'au include a time-series sediment trap tripod, a single sediment trap tube, and a wave gauge at 10 m (33 ft) depth. A time-series sediment trap consists of a series of bottles that rotate beneath a funnel. A computer and motor rotate the bottles underneath the funnel at a pre-determined interval so that scientists know how much sediment is collected during a particular time frame. The instruments are monitored quarterly. See Stop 12 for a description of sediment tube traps; see Stop A for a description of wave gauges.

Stop C: Kamiloloa – *21.0682 degrees N, 157.0009 degrees W*

The area offshore from the Hotel Moloka'i was chosen as a CRAMP site for the project because it was hypothesized that it would represent the "middle" endmember for Moloka'i's coral reef, only moderately affected by along-shore currents and sediment deposition. CRAMP monitoring transects are spaced at 3 m (10.5 ft) and 10 m (33 ft) depths. Both biological transect and photoquadrat CRAMP baseline data were collected in February 2000, and these locations are revisited annually to monitor change. Initial results show that this stretch of the coral reef is in very poor health. In most areas we find less than 5% live coral. It appears that this degraded area stretches approximately from the Kaunakakai Wharf to offshore near One Ali'i. The USGS is focusing attention on the Kamiloloa fore reef to map the extent of the area affected and to determine the cause of the problem, whether natural or man-made.

Additional instruments on the Kamiloloa fore reef include a rotating sediment trap tripod, a single sediment trap tube, and a wave gauge at 10 m (33 ft) depth. Another wave gauge and single sediment trap tube have been deployed at 4.5 m (15 ft) to characterize oceanic conditions nearer to the reef crest. The instruments are monitored quarterly. See Stop 12 for a description of sediment tube traps; see Stop A for a description of wave gauges; see Stop B for a description time-series sediment traps.

In July 2001 a second REEFPROBE tripod was deployed on the Kamiloloa fore reef at a depth of 7.5 m (25 ft). A short-term experiment, REEFPROBE#2 will be retrieved in November 2001. Data from this experiment will be compared to data collected on the Kamiloloa reef flat from REEFPROBE#1 during the same timeframe to look for across-reef trends of sediment flux and gradients. See Stop 12 for a description of REEFPROBE tripods.

Stop D: Kakahaia – *21.0587 degrees N, 156.9420 degrees W*

In an effort to monitor coral reef habitats near to the suspected source of sedimentation problems, several CRAMP photoquadrat sites were established on the Moloka'i reef flat in 1 m (3 ft) of water. This site at Kakahaia was chosen because it appears to be a transition zone along an east-west sediment gradient, and it is easily accessible from shore. Baseline photographs were collected in February 2000. The location is revisited annually to detect change on a colony-level. Additional CRAMP photoquadrat sites on the reef flat are found at Pala’au (Stop B) and Kamiloloa (Stop 12).

Stop E: Kamalo – *21.0375 degrees N, 156.8976 degrees W*

Offshore just to the west of Kamalo Harbor is the location of CRAMP biological transects in 3 m (10.5 ft) and 10 m (33 ft) of water. This site was chosen for the project to represent the healthy endmember for Moloka'i’s coral reef. Previous dive surveys by USGS scientists showed this area of the fore reef to be in excellent health with >90% coral coverage and few sedimentation problems. CRAMP baseline data was collected in February 2000. The location is revisited annually to detect change. A single sediment trap tube was first deployed in February 2000 at the 10 m (33 ft) site and is monitored quarterly. See Stop 12 for a description of sediment tube traps.

Kamalo Point is exposed to the northeast trade winds and also receives some of the north Pacific swell waves as they are diffracted around the east end of Moloka'i. In an effort to characterize the wave energy regime and how it affects the fringing reef, a wave gauge with a battery-operated data logger was deployed at a water depth of 10 m (33 ft) in February 2001. Data are downloaded from the logger quarterly (turnaround time is determined by battery life). See Stop A for a further description of wave gauges.

Stop F: Puko'o – *21.0607 degrees N, 156.7937 degrees W*

The Puko'o area is directly exposed to the northeast trade winds and also waves from the north Pacific swell as they are diffracted around the east end of Moloka'i. In an effort to characterize the wave energy regime and how it affects the fringing reef, a wave gauge with a battery-operated data logger was deployed at a water depth of 10 m (33 ft) in February 2001. Data are downloaded from the logger quarterly (turnaround time is determined by battery life). A sediment trap tube was attached to the wave gauge in April 2001 and is monitored quarterly at the same time as the wave gauge. See Stop 12 for a description of sediment trap tubes; see Stop A for a further description of wave gauges.

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