Hawai‘i’s Coastline:

Chapter for the World’s Coastline

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Source of base maps: 10 m USGS DEM’s

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Introduction

The Hawaiian Hot Spot lies in the mantle under, or just to the south, of the Big Island of Hawai‘i, where two active subaerial volcanoes and one active submarine volcano reveal its productivity. Centrally located in the Pacific plate, the hot spot is the singular source of the Hawaiian Island Archipelago and its northern arm, the Emperor Seamount Chain. This system of islands and associated reefs, banks, atolls, and guyots spans over 30º of latitude across the Central and North Pacific Ocean to the Aleutian Trench, and contains at least 107 separate shield volcanoes (Clague and Dalrymple 1987). The trail of islands increases in age with distance from the hot spot and reflects the dynamic nature of the Pacific plate, serving as a record of its paleospeed and direction over the Hawaiian hot spot for the last 75-80 my (Clague and Dalrymple 1987). A major change in plate direction is marked by the northward kink in the chain at the end of the Hawaiian Ridge approximately 3,500 km from the site of active volcanism (Moore 1987). Today the Pacific plate migrates northwest at a rate of about 10 cm a year away from the hotspot at the southeast corner of The Big Island (Moore 1987). The eight main islands in the state: Hawai‘i, Maui, Kaho‘olawe, Lāna‘i, Moloka‘i, O‘ahu, Kaua‘i, and Ni’ihau, make up 99% of the land area of the Hawaiian Archipelago. The remaining one percent exists as small volcanic and carbonate islands offshore of the main islands, and to the northwest.

Building Volcanoes in Hawai‘i

The main bodies of the Hawaiian Islands are great shield volcanoes built by successive flows of pāhoehoe and ‘a‘ā basalt lavas that evolve through a recognized sequence of morphological and chemical stages (Clague and Dalrymple 1987).

Alkalic basalts dominate the earliest submarine pre-shield building stage; with a transition to tholeiitic basalt that occurs as the volcano grows and approaches sea level. Loihi seamount, on the southeast flank of Mauna Loa Volcano on the Big Island, is an example of this stage. Loihi rises over 3000 m from the sea floor and erupts hydrothermal fluids at its summit and south rift zone. Loihi's current growth rate may allow it to emerge above sea level in the next few thousand years.

The subaerial main shield building stage produces 98-99% of the lava in Hawai'i. Kīlauea Volcano on the southeast flank of Mauna Loa on the Big Island, is actively undergoing shield building. Kīlauea Volcano alone has produced ~2km^3 of lava since 1983 (Garcia et al. 2000). The main shield building stage produces tholeiitic lavas of basalt and volcanic glass with olivine, clinopyroxene, and plagioclase as the primary crystal components.

Declining eruption rates accompany the onset of a post-shield building stage. This stage marks the end of active volcanism and is dominated by massive flows of 'a'ā, and marked by a shift back to alkalic lavas that typically cap the top of the shield.

In some cases, after lying quietly in erosional conditions for thousands-to millions of years, some Hawaiian volcanoes experience a rejuvenation stage of eruptions, from a distinctly different source. These silica-poor alkalic lavas typically contain combinations of nepheline, olivine and clinopyroxene with either melilite or plagioclase. Post-erosional rejuvenated eruptions are more explosive than the less viscous eruptions of the shield building stage, commonly producing cinder and tuff cones around the active rift zones, and vents atop the eroding older shields. Three edifices on the island of O'ahu: Diamond Head,

Koko Head, and Koko Crater are the result of this process.

Although this is the classic sequence for Hawaiian shields, an individual volcano may become extinct during any of the phases, ending the evolution of that particular shield (Moore 1987).

Sand and Detritus at the shoreline

Hawaiian carbonate sand is mainly a creamy white calcareous mix, derived from the tests of microorganisms, weathered coral, calcareous marine algae, and mollusk shells (Harney et al. 2000). The black and green sand beaches on the islands are derived from eroded volcanic material. Where volcanism is active, black sand is produced at sites of littoral volcanic explosions at the coast, where lava flows into the ocean. Lava entering the ocean is instantly quenched from ~1300˚ C, resulting in glass that is crushed by waves into sand-sized grains. In Hawai'i, basalt is generally a secondary source of sand, but a primary source of detritus as the basaltic islands erode and material is transported to the coast. Green sand beaches contain enough olivine to acquire the color of the mineral, and occur where olivine is significantly weathered out of basalt in the backshores of beaches. Ferromagnesian olivine and other basaltic minerals are relatively unstable in the tropical climate of Hawai'i, eroding quickly folloing exposure. Calcareous beaches are dominant on all the older Hawaiian Islands where significant coral reef communities have been able to develop (Moberly and Chamberlain 1964). Though there are flurishing reef systems around the older Hawaiian islands much of the sand may have been produced at earlier times (up to 5000 yr B.P. in Kailua Bay on O'ahu) (Harney et al. 2000).

The coastal plain of most Hawaiian Islands holds major land based sand reservoirs, of variable volumes, in the zone between approximately 1 m below

sea level and 2 – 3 m above sea level. These sands have been radiocarbon dated in the range 1000 to 4000 yrs BP. Their position is a function of late Holocene high sea levels dating from the same period, and persistant eolian deposition under seasonal winds (Fletcher and Jones 1996; Grossman et al. 1998). Shore-normal reef channels that are partially filled with sand augment beach sediment budgets. Longshore transport dominates sediment movement along the coast in distinct littoral cells. Both offshore sand reservoirs as well as erosion of coastal plain sandstones play important roles in the seasonal and storm-related erosion and accretion of Hawaiian beaches. Offshore sand reservoirs exist in natural channels cut in fringing reefs around the islands during lowered sea levels, and in innumerable shallow ref flat depressions formed by karst action during periods of subaerial exposure (Moberly 1964).

Terrigenous sediment in localized coastal stream and river deltas may be reworked and provide a locally important source for neighboring beaches. In general, the carbonate beaches of Hawai'i are the leading frontal edge of coastal plain sand deposits dating to the late Holocene Kapapa Stand of the sea (+2 m), although localized exceptions to this rule abound.

Wind and Waves

The central pacific location of the Hawaiian Islands exposes them to wind and ocean swells from all directions. The Islands' relative locations however, may provide rain, wind, and wave shadows, that create unique exposures of coastline that are either protected from, or vulnerable to, wind and wave impact. One example of this type of relationship occurs in the Maui Group of islands, Maui, Lāna'i, Moloka'i, and Kaho'olawe. Here, Maui, elongated northwest-southeast, and Moloka'i, elongated east-west, provide substantial protection for

the north and east coasts of the smaller islands that lie in their lee: Lāna‘i and Kaho‘olawe. The north coasts of these islands lack significant sea cliff development and are low-lying. This morphology directly reflects these islands protection from prevailing winds and strong seasonal storms in the north Pacific (Macdonald et al. 1986).

The north shores of the Hawaiian Islands are best known for world-class surfing conditions that persist in the winter between October and March. Long period swells (12-20 seconds) derived from energetic sub-polar and mid-latitude storms in the north Pacific bring waves to the north coasts (282°-45°). These waves average 1.5 – 4.5 m in height, with extraordinary extreme wave heights of up to 15 m, and an annually recurring maxium significant waveheight of approximately 7.5 m. North shore waves break over near and offshore fringing reef systems, with faces twice the height of the waves, creating tubular and A-frame waves, and strong (dangerous) rip currents at the shoreline (Fletcher et al. 2002).

Hawai‘i is located in the tropical latitudes and northeast trade winds dominate, consistently blowing15–30 km/h, with periods of exceptionally strong and gusty winds up to 65–95 km/hr. Short period wind swell (6-8 seconds) generates waves that break over fringing and outer reef systems exposed on the windward side of the islands, heralding average wave heights of 1–3. m, with greater heights associated with particularly strong wind events. The trade winds prevail approximately 70% of the year, with maximum intensity and consistency between April and September.

Exposed south and west facing shores (258°-147°) are subject to Kona storms that dominate mainly during periods of weakened trade wind activity.

Kona storms occur less than 10% of the year, generating long and moderate period waves (6-10 seconds) that are steep faced typically reaching heights of 3–4.5 m.

South and southwest (210-147°) coasts are also impacted by storms of the south Pacific that are associated with southern hemisphere winter season: April through October. These strong storms blow over long fetches and generate waves that travel thousands of kilometers to reach Hawaiian shores, arriving 53% of an average year. These long period swells (12-20 seconds) occur most regularly and with the most power in the summer when waves averaging 0.3–1.8 m high, bring abundant recreational opportunities and, refreshing surf to the south shores during the hot summer months.

Sea Level

Local relative sea level in Hawai'i is not only dependent on global eustatic trends (which at the time of this writing is +2 mm/yr.), but is also affected by subsidence of the oceanic lithosphere, which responds elastically to volcanic loading over the hotspot. It is estimated that one half of the upward building of Hawaiian volcanoes is reduced by subsidence and that most of the volcanoes have subsided 2–4 km since emerging above sea level (Moore 1987).

The main Hawaiian Islands span ~5 my in age, and are at differing distances from the hot spot foci of subsidence, thus they are each at unique stages of subsidence. The result is that the islands experience different relative sea levels. These relative differences in sea level are demonstrated by modern tide gage rates and support the view that subsidence is active over the hot spot (Moore 1987).

Evidence such as: submerged wave cut notches and benches, raised coral

reef, subaerial marine terraces, and entire coastlines of alluviated river valleys can be found at different elevations and locations around the state. These types of evidence, found around the islands, indicates that Hawaiian shorelines have been drowned and reestablished with eustatic trends and island-specific vertical movement. The fossiliferous marine conglomerate 80 m above sea level on south Lāna‘i, are typical examples of indicators of past stands of the sea (Rubin et al. 2000).

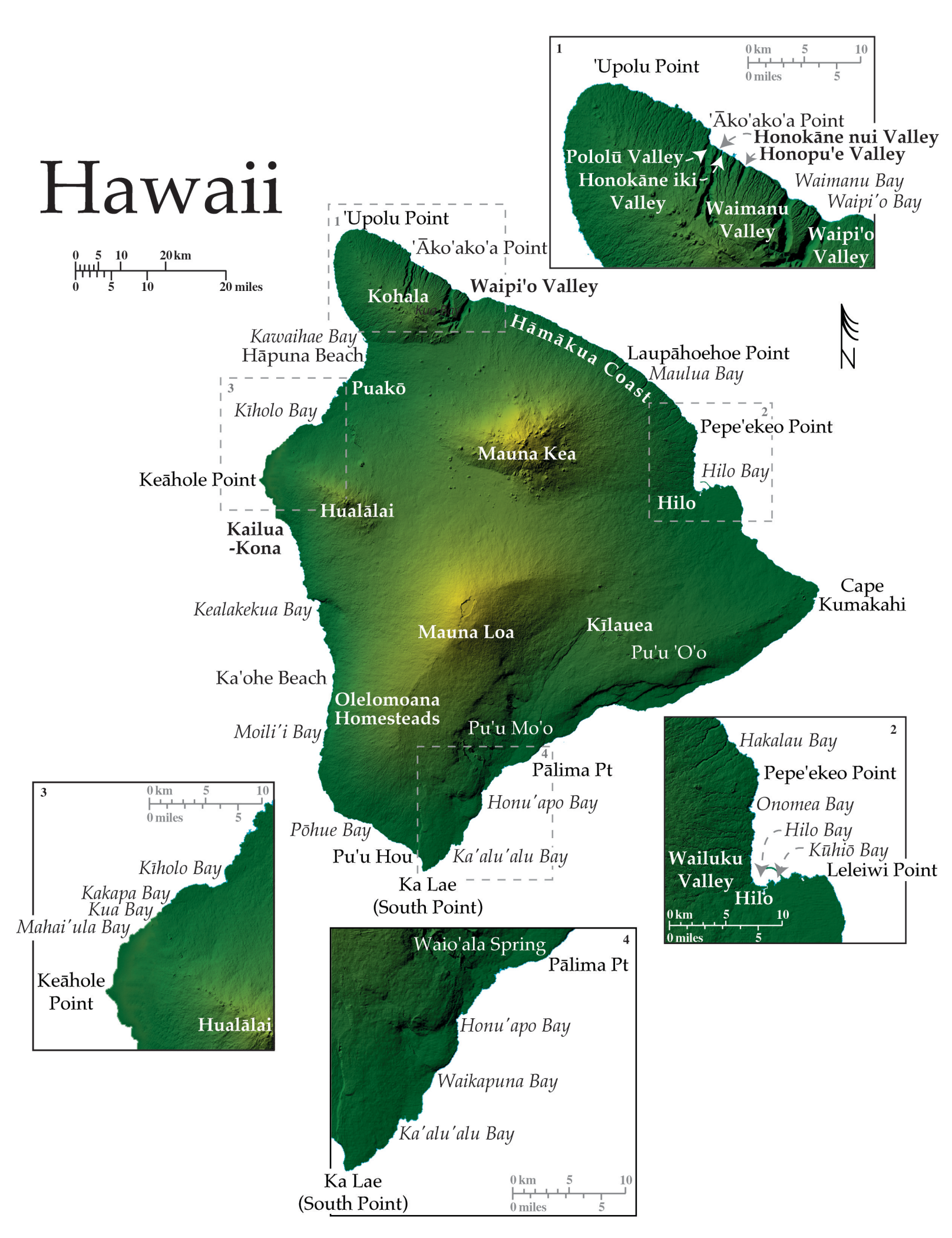
Holocene sea level has been influenced both by eustatic postglacial meltwater as well as equatorial oceanic siphoning associated with the changing postglacial geoid (Mitrovica and Milne 2002). These lead to a highstand approximately 2 m above present ca. 3000 yr BP followed by se level fall culminating in the pre-modern period. Tide gages record sea level rise since only 1900 in Hawai‘i.

Erosion

The Hawaiian Islands are experiencing widespread but locally variable coastal retreat in response to a history of human interference with sand availability and the inferred influence of eustatic rise. In pristine coastal areas calcareous sand stored on the low-lying coastal plain is released to the beach as sea level rises, allowing the beach to maintain a wide sandy shoreline even as it migrates landward.

Coastal property in many areas of Hawai‘i is at a premium, and the encroachment of the Pacific Ocean onto multimillion-dollar residential and commercial lands and development has not gone unnoticed by landowners. The response in many cases has been an armoring of the shoreline. Artificial hardening of the shoreline is a form of coastal land protection that occurs at the

expense of the beach where there is chronic recession, preventing waves from accessing the sandy reservoirs impounded behind the constructed coast. Thus, efforts to mitigate coastal erosion have created a serious problem of beach erosion and beach loss along many shorelines in the state, particularly on the most populated and developed islands (Fletcher and Jones 1996). The need to address this issue is acknowledged by the state and local communities, and the hope is that a broadly scoped management plan will keep the Hawaiian shorelines in balance: between the natural coastal morphology and human resource needs.


Hawaii
0 5 10 20 km
0 5 10 20 miles
1
'Upolu Point
'Āko'ako'a Point
Waipi'o Valley
Kohala
Kawaihae Bay
Hāpuna Beach
Hāmākua Coast
Laupāhoehoe Point
Maulua Bay
3
Puakō
Kīholo Bay
2
Pepe'ekeo Point
Mauna Kea
Hilo Bay
Keāhole Point
Hualālai
Hilo
Kailua
-Kona
Cape
Kumakahi
Kealakekua Bay
Mauna Loa
Kīlauea
Pu'u 'O'o
Ka'ohe Beach
Olelomoana
Homesteads
Moili'i Bay
Pu'u Mo'o
4
Pālima Pt
Honu'apo Bay
Pōhue Bay
Pu'u Hou
Ka'alu'alu Bay
Ka Lae
(South Point)
1
'Upolu Point
0 km 5 10
0 miles 5
'Āko'ako'a Point
Honokāne nui Valley
Honopu'e Valley
Pololū Valley
Honokāne iki
Valley
Waimanu Bay
Waipi'o Bay
Waimanu
Valley
Waipi'o
Valley
N
3
0 km 5 10
0 miles 5
Kīholo Bay
Kakapa Bay
Kua Bay
Mahai'ula Bay
Keāhole
Point
Hualālai
2
Hakalau Bay
Pepe'ekeo Point
Onomea Bay
Hilo Bay
Kūhiō Bay
Wailuku
Valley
Leleiwi Point
Hilo
0 km 5 10
0 miles 5
4
Waio'ala Spring
Pālima Pt
Honu'apo Bay
Waikapuna Bay
Ka'alu'alu Bay
Ka Lae
(South Point)
0 km 5 10
0 miles 5

The Island of Hawai'i lies over or just north of the Hawaiian hot spot and is composed of five volcanoes and one active seamount: Kohala, Hualālai, Mauna Loa, Kīlauea, Mauna Kea and Loihi located offshore. Of these, only Mauna Loa, Kīlauea, and Loihi are considered active, while Haulālai is dormant with its most recent eruption ending sometime in 1800-1801. The island has 428 km of general coastline and is so large relative to the other Hawaiian islands, it is known locally and abroad as the Big Island.

On the Big Island, well-developed black and green sand beaches signify the active reworking, by waves and currents, of the freshest lavas in the state. The island's youth has, in general, allowed for a lower degree of beach formation along its rough volcanic coastline. White calcareous beaches make up a relatively small component of the shoreline largely because of poor reef development due to recent active coastal volcanism.

The orographic effect of the Big Island's large shields: Mauna Loa (4,169 m), Mauna Kea (4,205 m), and Kohala (1,670 m) create a lush region on the northeast side of the Big Island, where annual rainfall is 150–400 cm.

The Puna District comprises the eastern most corner of the Big Island, reaching out at Cape Kumakahi, a broad rocky point with a shallow slope at the coast. This area was resurfaced during the 1960 flow originating from Kīlauea's east rift zone. The flow narrowly missed the navigational light on the


Cape Kumakahi
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point as it remarkably divided into streams and flowed around the lighthouse (Clark, 2002).

North of Cape Kumukahi the coast extends for roughly 25 km around Leleiwi Pt. into the Hilo District and Hilo Bay in a series of wave weathered low rocky sea cliffs, and rough remnant lava flows. Hilo Bay is one of two deep draft harbors on the Big Island. The bay is the seaward end of the Wailuku River valley that runs along the junction between the younger Mauna Loa lavas to the south and older Mauna Kea lavas to the north. A breakwater 3 km long extends offshore from a large natural deep water gap in the fringing reef of Kūhiō Bay. The structure runs west in front of the developments fronting eastern and central Hilo Bay. Hilo is a heavily populated coastal city that was devastated in both 1949 and 1960 by tsunamis originating as earthquakes in the Aleutian trench and along the Chilean coast respectively (Fletcher et al. 2002). In 1984 Mauna Loa broke a nine-year period of quiescence sending lava flowing down to the northern city limits, a reminder of the volcanic hazard in this coastal city (Fletcher et al. 2002).



The Pepeʻekeo-Hāmākua Coast stretches for 100 km between Hilo and Waipiʻo Valley to the north. This northeast and northern exposed coastline consists of a steep rocky shoreline of Mauna Loa lavas, characterized by a

multitude of headlands, sea cliffs (~30-90 m high), coves, and irregular embayments such as: Onomea, Hakalau, and Maulua bays. The Hāmākua



coastal embayments are seaward ends of stream carved gulches that originate upland on the lush Mauna Kea mountainside, and are a passage to the coast for water rich with sediment, soil, and eroded volcanic rock. Black volcanic pebble and cobble stone beaches line the bay heads, and large blocks of fluvially transported basaltic debris along the shoreline lie where they have been scattered by high-energy waves. No fringing reef has developed along this relatively young shoreline, however offshore rocky islets are commonplace along the northeast coasts of the Big Island; totally exposed to north Pacific trade wind seas.

Waipiʻo Valley, in the far northeast, marks the junction where Mauna Kea lavas to the south overlie lavas of the broad and elliptical Kohala Volcano (1,670 m) to the north. Kohala is the Big Island's oldest shield, projecting northwestward and forming the northernmost portion of the island. Waipiʻo Valley is the first, and most immense (approximately 1 km wide), of seven spectacular shore-normal amphitheater valleys that extend northwest along the Kohala coast. These valleys developed during a lower stand of the sea (~90 m), and were partly filled with alluvium at that time. As sea level rose the alluvium was reworked and the modern low lying, scenic wetland valley floors that lie

inland of the coast were created (Macdonald et al. 1986).

The valleys, such as: Waimanu, Honopu'e, Honokāne Nui/Iki and Pololū, are bordered by steeply ascending massive rock walls. Except for a four-wheel drive road into Waipi'o, access to the lush valley floors is limited to foot trails or boats. Dynamic beaches dominated by black volcanic sand, line the seaward end of the northeast Kohala valleys. Between the largest of the amphitheater valleys, the coast is dominated by blunt sea cliffs that rise to 400 m above the ocean, the truncated remains of the shield that once extended at least a kilometer into the ocean. The cliffs are incised by numerous stream cut canyons 300-750 m deep that form a series of narrow coastal hanging valleys (Macdonald et al. 1986). This area represents the only coastal segment of Kohala that was spared resurfacing by the Hawi Volcanic Series toward the end of the Kohala main shield building stage when Hawi lavas flowed over most of the eroding shield (Macdonald et al. 1986).





North of Pololū Valley, the east Kohala coastline is made up of steep lava headlands and

irregular low lying rocky embayments where streams enter the ocean out of wetland gulches. Like the shoreline to the south, small rocky sea stacks lie offshore of eastern Kohala, isolated from the retreating coast by heavy North Pacific surf (Fletcher et al. 2002). This coastal morphology, with the addition of sparsely distributed cobble and boulder beaches, extends from the exposed northern tip of the island at ʻUpolu Pt. around to Kawaihae Bay and Harbor at the western intersection of the Kohala and Mauna Kea shields.

The western side of the Big Island lies in the lee of Mauna Loa (4,205 m), the largest volcano on Earth (measuring from the sea floor), which has formed in the last 600,000-1,000,000 yrs, rising almost 9 km from the sea floor. The leeward climate is extraordinarily dry with 25 cm annual rainfall, and minimal stream erosion on the Hawi lavas of western Kohala, and on the lavas of Mauna Kea, Mauna Loa, and Hualālai, south along the coast respectively. Kawaihae Harbor is the second deep draft harbor on the Big Island and is fronted by a system of offshore fringing reefs. Several sand beaches exist at the south end of Kawaihae Bay, derived from eroded coral that was dredged during construction of the harbor.


Kawaihae Harbor
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Approximately 5 km south of Kawaihae, along a shoreline of bright golf course greens and hotel development, lies Hāpuna Beach, the widest of the few

well-developed calcareous sand beaches on the Big Island. The Puakō coast, lies just south of Hāpuna Beach, along the coast that was extended by historic Mauna Loa eruptions. Renowned for its tide pools at the shoreline and well-developed offshore fringing reef, the Puakō coast is a popular scuba dive destination.

Hualālai Volcano (2,521 m) makes up the central western coast of the Big Island. Now a dormant volcano, it last erupted in 1800–1801, burying an ancient Hawaiian village along the northwest coast. From the western banks of the shallow coastal lagoon at Kīholo Bay, the Hualālai coast extends southwest and is rocky and shallow sloped. Offshore fringing reef and pocket sandy beaches line the numerous embayments including: Kakapa, Kua, and Mahai'ula Bays along this coast.

Lavas of the most recent Hualālai eruptions make up the coast from the south side of Mahai'ula Bay to the western tip of the island at Keāhole Pt. This shoreline is characterized by low rocky headlands fronted by fringing reef, small rocky remnants offshore, and beautiful tide pools and beaches (both black and white) along the shore. The coastline of historic Hualālai lava extends less than 30 km south of Keāhole Pt., beyond Kailua-Kona to the small non-distinct west facing Kuamo'o Pt. Lavas of the southwest Mauna Loa rift zone extend beyond Kuamo'o Pt. to the south point of the island. The South Kona district has a coastline rich with relics of historic


Kealakekua Bay
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Hawaiian habitation. Much of this coast is low-lying historic lava that has been gradually invaded by hardy vegetation. In contrast, Kealakekua Bay is an area along this coast that contains steep cliff walls that reveal the layered nature of their basalt. The bay is accessable only by boat or foot trail and harbors one of the State's underwater parks. This 315-acre marine conservation district is lined with a vibrant healthy reef ecosystem (Clark 2002). Abundant fish swim about the shallow corals that dip steeply away from shore toward deeper water. The bay is the location where Captain Cook moored for reprovisioning, and ultimately his death.

Between Ka'ohe and Moili'i, streaks of relatively recent flows (1950's) extend to the coast from the volcano. Here tide pools at the shoreline are generally formed of lava spits in various stages of erosion. These areas are mainly accesable by 4x4 roads and are devoid of development.


Lava coast near Ka'ohe
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Because of its relative youth, the Mauna Loa coastal terrace of the southwest coast has lower degrees of soil development. In its absence, subsurface streams fed by upland precipitation penetrate the relatively young porous basalt. These conditions have created a system of sub-surface fresh water flows that feed wetlands and offshore freshwater seeps along southwest coast of the Big Island from Miloli'i to Ka lae Pt. The shoreline from Moili'i to Ka lae Pt.

is made up of shallow and moderately sloped headlands and low sea cliffs, and is backed by numerous wetlands areas fed by the underground freshwater flows. Beaches of the southwest coast are almost exclusively black sand. Several cones of cinder and ash lie just inland of the southwest shore and were built by littoral explosions during historic sea entries of Mauna Loa lavas (Macdonald et al. 1986). The most recent flows of 1868 produced Pu‘u hou a cinder cone rising 72 m from the shoreline. Wave erosion has truncated the cone, resulting in a beach of red cinder at its base. Olivine sand beaches skirt the rocky headland coasts of south Hawai‘i produced by the fresh erosion of the island’s basalt.

Extending north from Ke lae Pt. the southeast coast is made up of steep rocky headlands that transition to a low-lying coastal plain in the region of Honu‘apo Bay. This geologically complicated area has been impacted by historic tsunamis and general tectonic subsidence. The Kīlauea southwest rift zone cuts through the coastline into the seafloor several kilometers northeast of Waio‘ala Spring, at Pālima Pt. marking the end of the wetland areas of south Mauna Loa and signaling the start of the Kīlauea coastline.



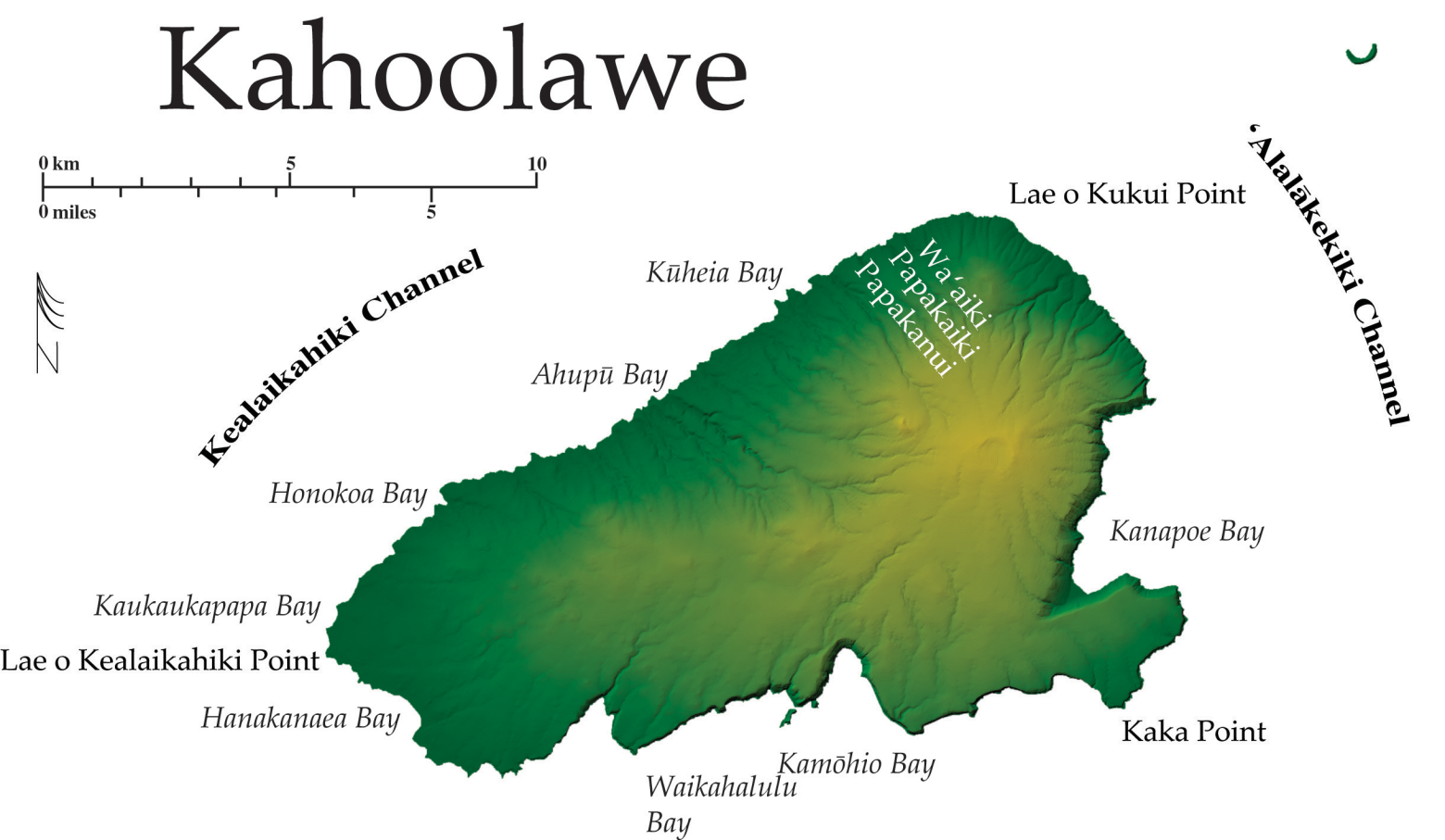
Kīlauea Volcano is a large bulge on the southeast flanks of Mauna Loa although it is an independent volcano with its own magma plumbing system. This volcano has been consistently active since at least the early nineteenth

century, if not since its emergence above sea level, continuously creating and redefining the coastal areas along east and southeast sides of the Big Island. On May 12th 2002, the Mother's Day Flow, commenced on the south flank of Kīlauea after issuing from a new vent near the southwest base of Pu'u 'ō'ō cone, 8 km upslope from the south east coast. As is typical of Kīlauea flows, the Mother's Day Flow travels as molten lava through preexisting lava tubes down the south flank of the volcano to the coastal plains. By late July 2002, two arms of the flow had reached the ocean, forming a broad lava delta that runs 570 m along the coast extending 50 m offshore of the West Highcastle coast, and a 1,540 feet wide lava bench that extends more then 300 ft offshore at Wilipea. Lava benches, such as at Wilipea, are a mechanism of island growth. These form as lava builds up repeatedly into thick and wide benches at the coast. Lava benches may collapse suddenly into the ocean, leaving behind sharp cliffs, and creating steam plumes of lava haze as seawater boils and vaporizes on contact with the rocks that may be hotter then 1100° C. These collapses may release water vapor, sulfur dioxide, chlorine gas, and fine shards of volcanic glass. Activity at the surface of Kīlauea reflects the dynamics at depth within the magma chamber that are recognized as earthquakes on the surface. They may mark movement of the south flank, as it



shifts steadily seaward at a rate of about 8-10 cm per year (Morgen et al. 1998).

Kahoolawe


0 km
5
10
0 miles
5
N
Kealaikahiki Channel
'Alalākekiki Channel
Lae o Kukui Point
Kūheia Bay
Wa'aiki
Papakaiki
Papakanui
Ahupū Bay
Honokoa Bay
Kanapoe Bay
Kaukaukapapa Bay
Lae o Kealaikahiki Point
Hanakanaea Bay
Kaka Point
Kamōhio Bay
Waikahalulu Bay

Kaho‘olawe is the smallest of the main Hawaiian Islands, with just 47 km of general coastline that wraps a single shield that formed 1.03 yr Ma. The island is aligned with the southwest rift zone of Haleakalā Volcano on Maui less than 10 km to the northeast, and may be related to the Hana Volcanic Series.

Kaho‘olawe has had a complicated history of human exploitation that has affected its terrain and environment, leaving it dry and barren. In the 19th and early 20th centuries, tens of thousands of sheep and goats were raised on the island. Consequent over grazing removed most of the islands vegetation leaving soil exposed to high winds, which eventually removed much of the topsoil. In 1939 the United States Military commandeered the island for use as a bombing and artillery target. Kaho‘olawe became the most artillery-impacted island in the Pacific from 1941 to 1945 (Clark 1989). Local efforts to return the island to Hawaiian control began in the mid seventies, and in 1993 the United States Congress turned Kaho‘olawe over to the State of Hawai‘i, and the Hawai‘i State Legislature established the Kaho‘olawe Island Reserve. The federal government commenced a cleanup campaign to remove the vast numbers of unexploded ordinance and debris that remain on the island and near shore areas. Because of its long-term status as a federal military site there have been few geologic investigations of Kaho‘olawe.

The north shore of the island extends with a northwest exposure for over 18 km from Kuikui Pt. at the north tip of the island to Kealaikahiki at the northwest tip. Along this coast flat pocket beaches of detrital sand lie at the mouths of stream gulches that reach to the center of the island. This coast lies in the lee of West Maui and is moderately protected from north Pacific swells. At the east end of the north shore small stream gulches such as Wa‘aiki, Papakaiki,

and Papakanui lie perpendicular to the coast where they drain from the islands interior during infrequent rainy periods. Larger gulches lie along the central north shore where they are separated by low vegetated rocky headlands. Rainy periods draw terrigenous material from the arid tops of the island to the coast where they cloud shallow nearshore waters. Deeper offshore waters are cleared by strong alongshore currents that are controlled by the Kealaikahiki Channel between Kahoʻolawe and Lānaʻi.

Larger beaches may be found at the heads of several larger bays along the coast such as Kūheia, Ahupū, and Honokoa bays. The western end of the north shore is lined with long, wide white sand beaches supplied by small patches of fringing reef both east and west of the large Honokoa Bay. These beaches extend to the western end of the north shore beyond the broad embayment north of Keanakeiki.

Kealaikahiki Pt. is a low-lying lava headland that lies at the north end of the west coast and is an important modern and historic navigational landmark. The west coast is less then 6 km long and consists primarily of a broad bay bordered to the south by a wide rocky headland. Hanakanaea Bay holds a long, wide white sand beach that slopes gently offshore making it one of the best landing sites for small craft on the island. Accessibility combined with generally calm conditions allowed nineteenth century opium smugglers to utilize the bay and to hide caches of the drug in the dry Kiawe vegetation that lines the backshore, thus the bay is also known as Smugglers Cove (Clark 1989).

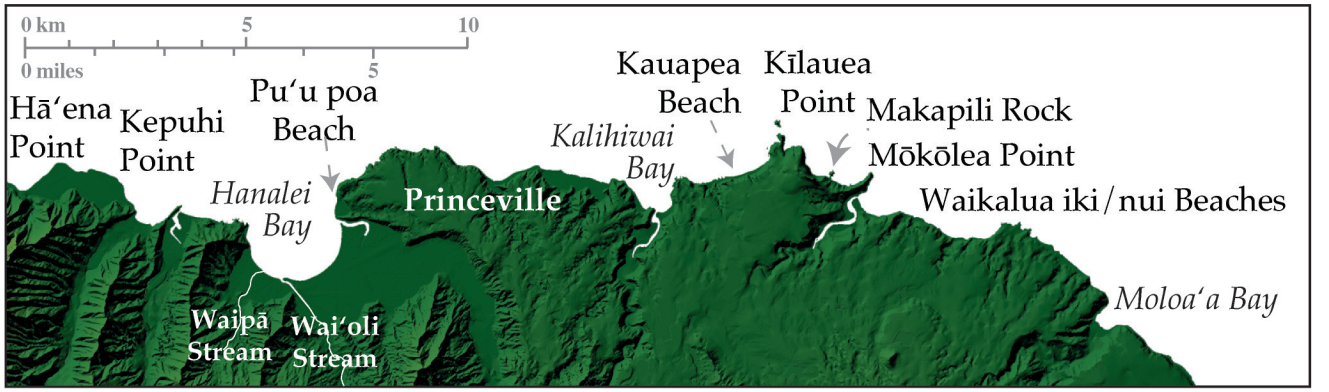
The south coast of the island is totally exposed to the ocean, and is irregular, carved into numerous embayments by large stream gulches. Two major embayments at Waikahalulu and Kamōhio reach far inland, and a large

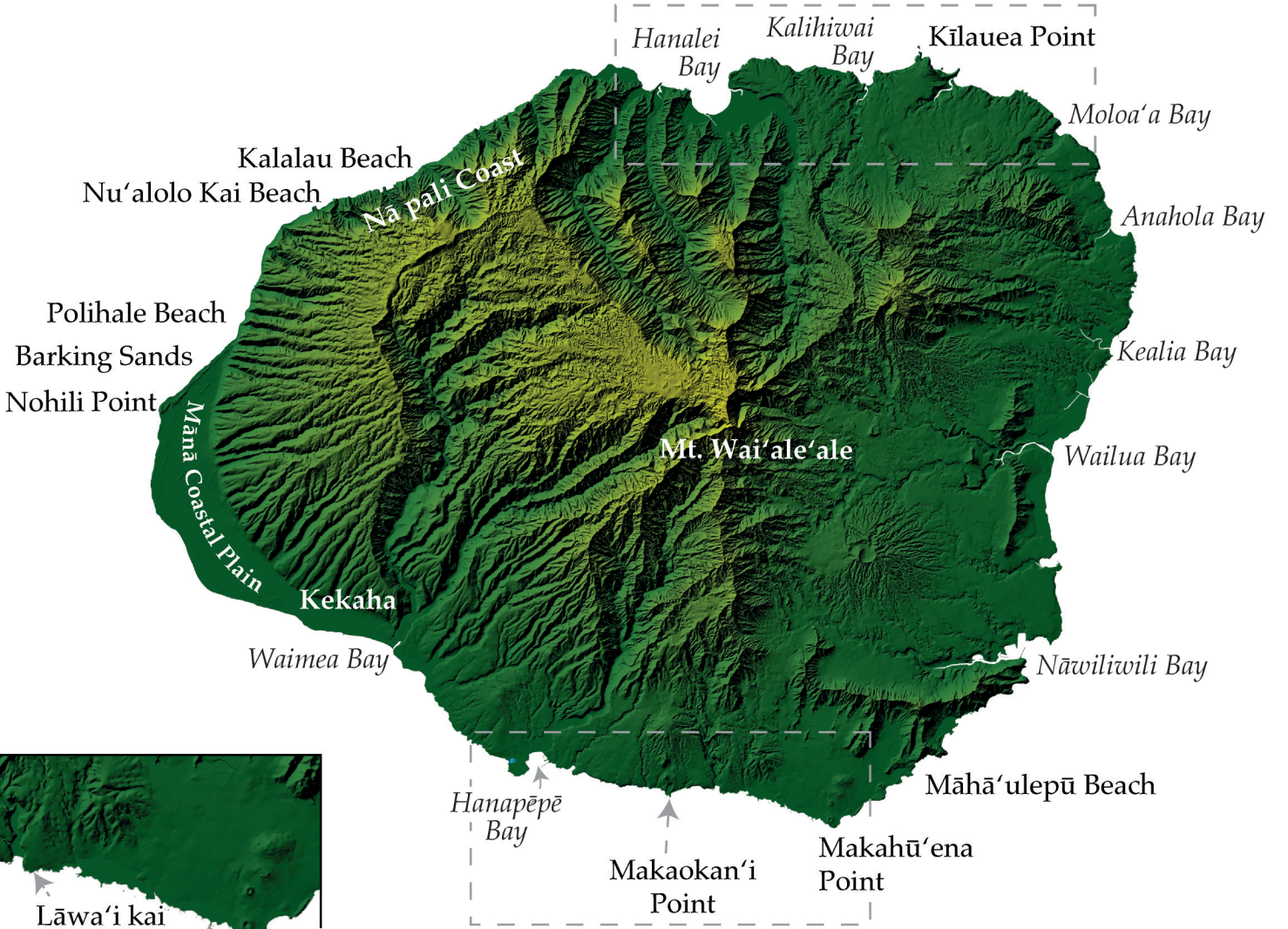
islet lies offshore of the central coast.

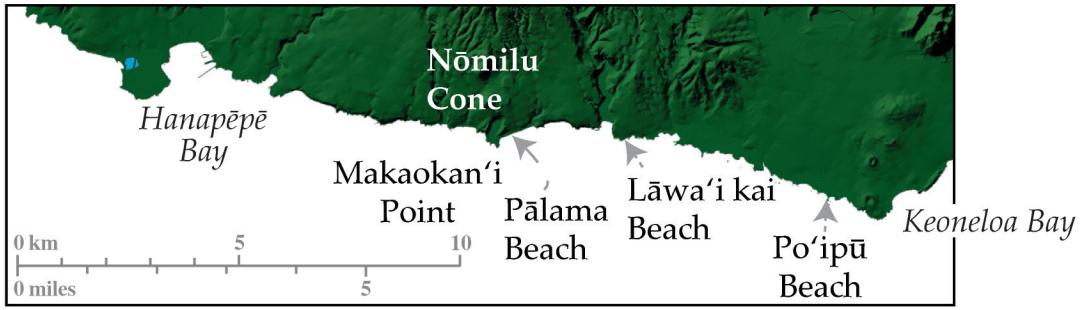
The east coast has been cut by wave erosion into blunt sea cliffs up to 240 m high that are essentially unaffected by stream erosion. Kanapou Bay is large: over 3 km wide, and is bordered by the walls of the old Kahoʻolawe caldera. This cross section of the eastern edge of the caldera is under-bedded by volcanic tuff and exposures of caldera-filling lavas lie in the head of the bay where they are massive with well developed columnar jointing. Rejuvinated eruptions at five vents along the caldera edge mantled portions of the eastern sea cliffs with spatter and cinder. Kanapou Bay holds a wide calcareous beach and dunes in the backshore. The nearshore waters are shallow but offshore the deep and fast waters of the ʻAlalākeiki Channel flow rapidly.

Kaua‘i


0 km
5
10
0 miles
5
10


0 km
5
10
0 miles
5
Hā‘ena Point
Kepuhi Point
Pu‘u poa Beach
Hanalei Bay
Princeville
Kauapea Beach
Kīlauea Point
Kalihiwai Bay
Makapili Rock
Mōkōlea Point
Waikalua iki/nui Beaches
Moloa‘a Bay
Waipā Stream
Wai‘oli Stream


Hanalei Bay
Kalihiwai Bay
Kīlauea Point
Moloa‘a Bay
Kalalau Beach
Nu‘alolo Kai Beach
Nā pali Coast
Anahola Bay
Polihale Beach
Barking Sands
Nohili Point
Kealia Bay
Mt. Wai‘ale‘ale
Wailua Bay
Mānā Coastal Plain
Kekaha
Waimea Bay
Nāwiliwili Bay
Hanapēpē Bay
Māhā‘ulepū Beach
Makaokan‘i Point
Makahū‘ena Point


Nōmilu Cone
Hanapēpē Bay
Makaokan‘i Point
Pālama Beach
Lāwa‘i kai Beach
Po‘ipū Beach
Keoneloa Bay
0 km
5
10
0 miles
5

Kaua‘i is the most northern island in the state, lying less than 30 km northeast of Ni‘ihau. Kaua‘i is over 5 million years old and has a roughly circular shape and 220 km of diversified. There are currently two models for the island’s morphology, a single shield model and a two-shield model.

More than 1.5 million years after the primary shield-building stage had ceased on Kaua‘i, rejuvenated volcanism, the Koloa Volcanic Series, began resurfacing two thirds of the eastern side of the island. Locations on the north, east and southern coasts of Kaua‘i contain lavas of the Koloa Series. Remnant volcanic vents trend generally north south across the Kaua‘i and may be found at a few locations on both the north and south shores.

Kaua‘i is known for the variety of microclimates that exist throughout the island including: temperate regions, dry sand dune complexes, and lush river valleys. The complex climate on Kaua‘i is created in part by the island’s high mountains. Mountains such as the centrally located Mt. Wai’ale’ale (1,569 m), trap moisture from the prevailing trade winds, creating vast amounts of rainfall and surface runoff that have carved deep canyons into the island. Mt. Wai‘ale‘ale is the tallest mountain on the island and receives an average of 11.4 m of rain each year, much of which drains northwest into the Alakai Swamp, one of the wettest places on earth.

The north coast, east of Hanalei, was thoroughly covered by rejuvenated lavas of the Koloa Volcanic Series and Koloa lavas make up the backshores of the modern beaches in this area.

The shoreline from Anahola to Hā‘ena is fronted extensively by large segments of fringing reefcut by paleostream channels. This shoreline is composed of a series of coarse-grained calcareous sandy beaches separated by

rocky points and interspersed with small stretches of boulder coast and numerous embayments.

Beaches such as Wailakalua iki and Waiakalua nui contain large pockets of sand, and are the seaward ends of mountain valleys that terminate dramatically at a low sloping coast. A classic Hawaiian waterfall cascades down the head of the valley behind Wailakalua iki, feeding a stream that flows across the beach into the ocean where nearshore waters are shallow and rocky.

West of Waiakalua nui lies Kīlauea Pt., the northern most point on the island and in the state. It is the namesake of the National Wildlife Refuge that holds 160 acres of rugged sea cliff coastline including Kīlauea Pt., Crater Hill, and Mōkōlea Pt. The area harbors several species of central pacific seabirds by providing safe nesting sites. Coastal vegetation endemic to Hawai'i has been planted throughout the refuge adding to the beauty and natural state of the area (Clark 1990).


Kīlauea Point lighthouse
Reproduced by permission of USGS: Series I-2761

Makapili Island lies just offshore and to the west of Kīlauea Pt. The island is formed of tuff and has been partially eroded by waves into a sea arch. Makapili is attached by a tombolo to the only tuff cone on Kaua'i, Crater Hill. The cone is made up of bombs and blocks of melilite nephelinite and fragments

of reef limestone, and is thinly laminated by spattery textured lava. The poorly sorted breccia base of the cone is the result of powerful steam explosions that occurred when the vent first opened (Macdonald et al. 1986).

Between the Kīlauea Pt. area and Princeville, to the west, lie several long, wide stretches of beautiful calcareous sand such as: Kauapea Beach: a pocket of sand 914 m long and almost 20 m wide that transitions to a boulder beach at the west end, inside Kalihiwai Bay. Offshore of Kalihiwai Bay, ~6 km east of Princeville, begins one of the largest shallow fringing reef systems in the state where the sandy shoreline at Kauapea transitions to a boulder beach at the west end inside Kalihiwai Bay ~6 km east of Princeville. The fringing reef extends over 480 m offshore and more than 3 km to the west, and offers moderate protection to the shoreline from powerful winter and spring storms. The reef narrows to the east and disappears in front of Princeville, where two natural calcareous pocket beaches and one longer sandy stretch of beach skirt the sea cliffs at the waters edge.

The beaches fronting the cliffs at Princeville are typically inundated by large winter surf that may create strong along shore currents. Regardless, these beaches are alluring attractions to the popular Princeville golf resort and residential neighborhoods that extend inland from the coast.

Pu‘u poa Beach extends from the west end of Princeville to the mouth of the Hanalei River, and is an effective barrier between Pu‘u poa marshland and Hanalei Bay opening to the north from the Hanalei coastal plain.

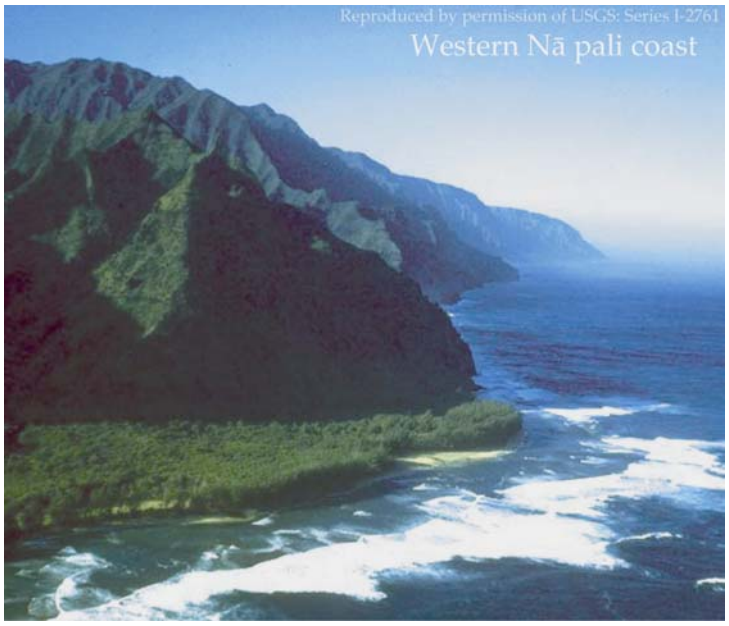
Hanalei is the largest bay on Kaua‘i and a popular surf spot. The bay contains a calcareous crescent beach along the shoreline that is over 3 km long and averaging almost 40 m wide in the summer. The sands here are mixed with

terrigenous sediments from the Hanalei, Wai'oli, and Waipā rivers that enter at 3 locations in the backshore of the bay.

The Hanalei interior plain is a fossil shoreline that developed during a higher stand of the sea between 1500 and 4000 yr BP (Calhoun and Fletcher 1999). The large Hanalei River gently meanders over the broad flat Hanalei Valley floor and is one of the few navigable rivers on the island; enjoyed by recreational kayakers and outrigger canoe paddlers.

The island's largest exposed layers of the rejuvenated Koloa Volcanic Series lavas are visible in the east wall of the Hanalei Valley, and are as thick as 650 m (Macdonald et al. 1986).

The Nā pali Coast State Park, along the northwest coast of Kaua'i,



contains some of the most isolated coastal lands in the state. The park extends along more than 24 km of coast that consists of steeply dipping knife-edge ridges and deep erosional V-shaped valleys. The ridges descend as narrow fingers directly to the ocean where they have been truncated into a spectacular sea cliff coastline. Access to this rugged coast is limited to an 18 km foot trail or boat, however north Pacific swells inhibit this option throughout the winter.

Nā pali translates to "the cliffs" in the Hawaiian language. The cliffs along this coast are evidence of the power generated by north Pacific swells that

may reach over 10 m in height before breaking against the island with explosive energy.

Pockets of calcareous sand that exist intermittently at the base of the Nā pali cliffs during the summer months are completely eroded in the winter and spring to reveal boulder beaches. Larger pristine calcareous beaches such as Kalalau and Nu‘alolo kai, which exist year round at the coast, are also eroded significantly in winter and spring.

The extreme steep sided valley walls of the Nā pali coast are covered with extensive vegetation supported by surface water draining seaward off of Mt. Wai‘ale‘ale. Fresh water cascades in many places hundreds of meters as waterfalls that create a lush seascape of vibrant green mountsides that drops into the sea.

The Nā pali formation, of the Waimea Canyon Volcanic series, was named for the exceptional views of shield building lavas afforded along this coast. The exposures dip gently toward the main caldera and have been revealed by tremendous erosion that has cut deeply into this part of the Kaua‘i shield (Macdonald et al. 1986).


Polihale Beach at the foot of the Nā pali cliffs
Reproduced by permission of USGS: Series I-2761

Kaua‘i’s west coast is in sharp contrast with the Nā pali coast, and the dramatic sea cliff coastline transitions abruptly into gently sloping wide beaches of calcareous

sands at Polihale State Park at the northern edge of the Mānā Coastal Plain. The broad Mānā plain extends over 16 km along the west coast and is skirted by one of the longest stretches of sandy beach in the state, which begins at Polihale and extends to Kekaha on the southwest coast. This sandy shoreline extends over 24 km, reaching widths of over 90 m in the summer with sand thicknesses up to18 m (Moberly and Chamberlain 1964).

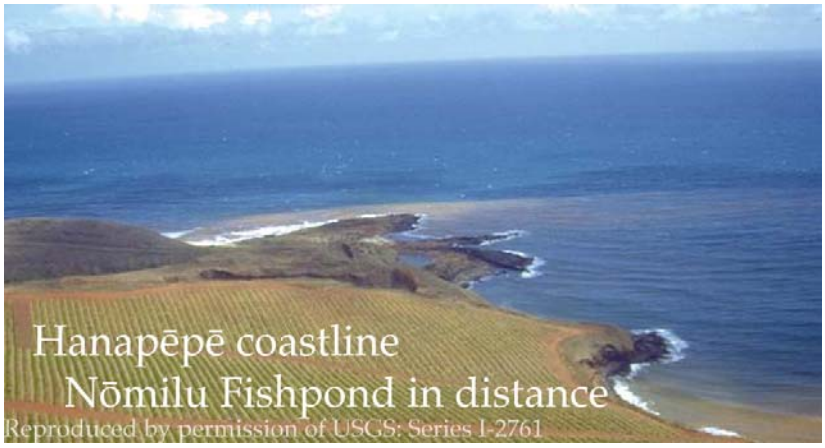


The dry extensive Mānā Plain extends less than 5 km inland to the foot of ancient sea cliffs from a higher Stand of the Sea. Mānā Plain is a Holocene accretional strand plain formed by the convergence of longshore sediment transport from the northeast driven by winter swell and trade winds, and from the southeast driven by summer swell and trade winds. The accretion process was likely aided by a fall of sea level at the end of the late Holocene Kapapa stand of the sea (ca. 3,000 yr BP). The seaward end of the Mānā Plain contains dunes of moderately to well-cemented calcareous sand, and behind the beach ridge, toward the interior plain, deposits of sand and gravel, marl and clay lay where they were deposited in a shallow lagoon. The clay beds are an excellent substrate for individual wedge-shaped buttons of twinned gypsum crystals that grow here, radiating in clusters (Macdonald et al.1986).

Some areas of the Mānā shoreline are fronted by beach rock and most of the continuous beach is backed by active sand dunes. A particularly large system of sand dunes (15 to 30 meters high) backs Nohili Pt. where wind erosion has also revealed sections of older lithified dunes. The larger dune area here is known as Barking Sands because of the abundance of hollowed calcareous grains that resonate sound when agitated or moved by the wind (Macdonald et al. 1986).

From the sands at Mānā Pt., to Makahū'ena pt at the southern tip of Kaua'i, the coast maintains a southwestern exposure. The general coastal slope steepens minimally beyond the Mānā Plain; the coast maintains a gentle slope until the steeper headlands of Po'ipū to the south.

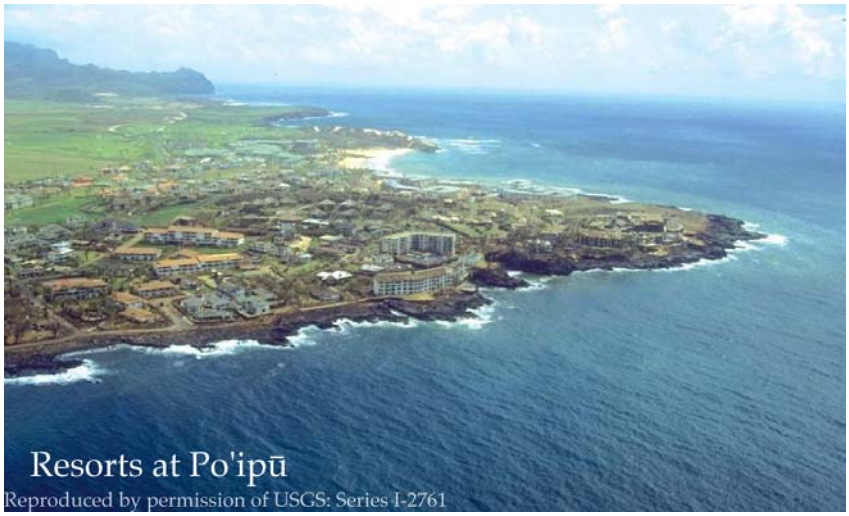
The southwest coast contains long, moderately narrow stretches of calcareous beach with a considerable detrital sand and sediment component. Detrital material is distributed by west flowing currents from the mouths of large river valleys such as Waimea and Hanapēpē that drain to the coast from the island's interior.



Lavas of rejuvenated volcanism inundated much of the central south coast from Kaumakani Pt. to Makahū'ena Pt. North-south trending clusters of vents lie just inland of the coast at Makaokaha'i Pt., and Makahū'ena Pt. at the south point of the island. One cinder cone of rejuvenated eruptions, Nōmilu Cinder

Cone, lies at the coast on the west side of Makaokahaʻi Pt. The cone holds a fishpond fed by a natural spring that is roughly 20 acres in size and over 20 m deep. The cone has been partially cemented with calcium carbonate by seawater, which enters and exits the pond with the tides (Clark 1990).

Between Nomilū Cone and Makahūʻena Pt., the Hunihuni coastal plain extends into the ocean as a mass of rejuvinated basalt. The interior plain is developed with the town and resort of Poʻipū. The shoreline in this area contains crescents and pockets of calcareous sandy beach such as Pālama, Lāwaʻi kai, and Poʻipū beaches. Patches of near shore fringing reef front the entire southwest shore between Nomilū and Poʻipū. The coast wraps the rocky headland at the southern tip of the island near Poʻipū where a tombolo extends from Poʻipū Beach to a rocky islet offshore. This section of shore bore the brunt of devastation related to Hurricane Iniki in 1992. Water levels, the product of storm surge and high tide on September 11 reached over 10 m above sea level and a maxium of 19 m (Fletcher et al. 1995).


Resorts at Po'ipū
Reproduced by permission of USGS: Series I-2761

Northeast of Makahūʻena Pt. lies a shoreline that is older and steeper than the relatively fresh basalt of the Hunihuni plain. Keoneloa Bay lies directly on the northeast side of Makahūʻena Pt. and Pleistocene eolionite cliffs lie in the backshore of the sandy beach. Beyond Keoneloa the coast extends over 3 km as a

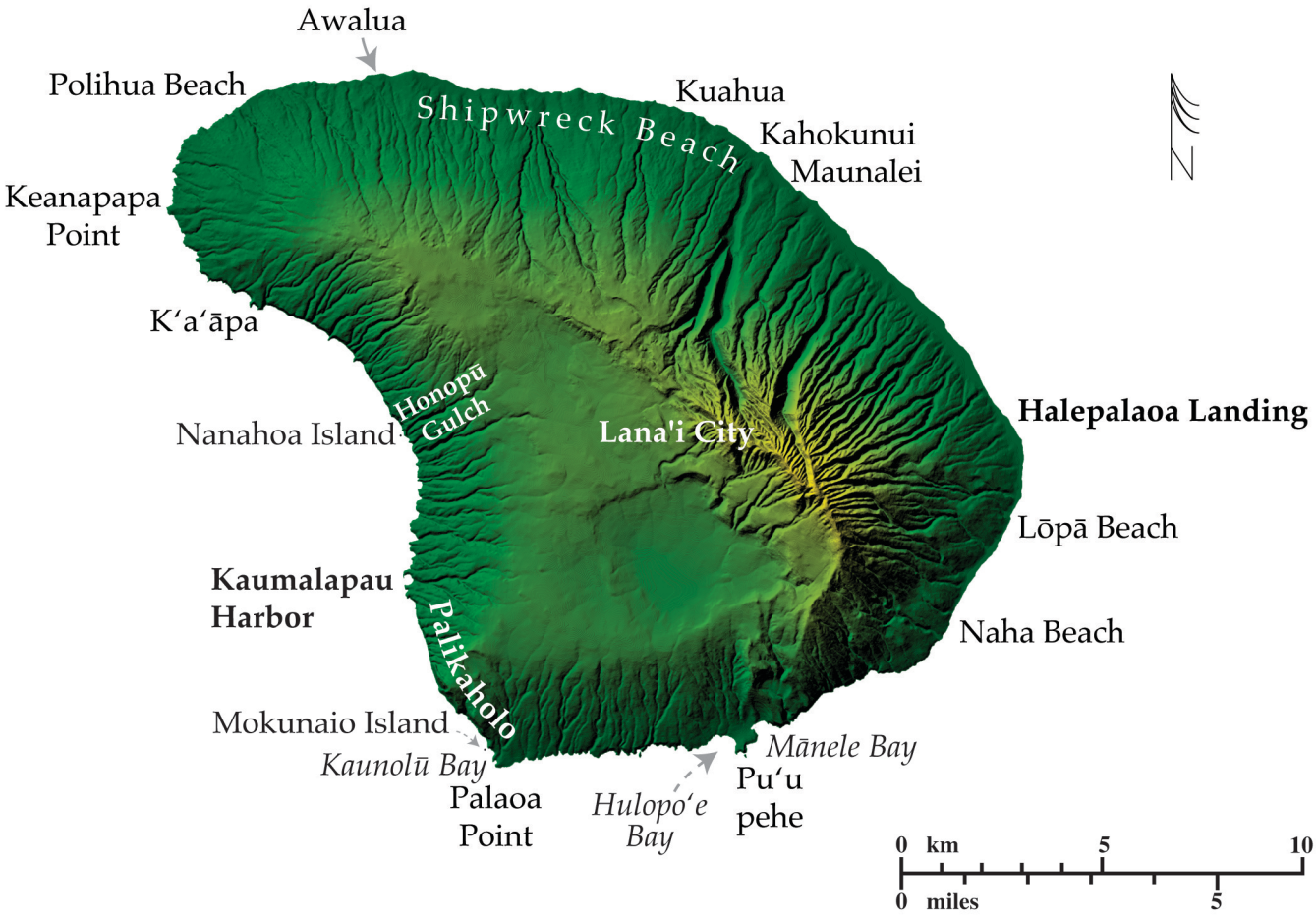
beautiful undeveloped winding shoreline known as Māhāʻulepū Beach. This stretch contains the heavily eroded remnant of a caldera on the flank of the main Kauaʻi caldera. Other remarkable features of Māhāʻulepū include lithified sand dunes, wave eroded nips and terraces, and limestone features such as sinks and caves that are the remains of karstified carbonate dunes (Clark 1990).

Northeast of Māhāʻulepū lies a gently sloping coastal plain of variable width that extends from the highly irregular embayment at Nāwiliwili bay and harbor to the far northeast coast of Kauaʻi at Kepuhi Pt. Streams and rivers flow into these embayed areas and are regularly overwhelmed with fresh water, promoting flooding at the coast. Well-developed fringing reef systems line the full extent of the shore, broken only by stream and river mouths.

Wailua and Kealia bays, along the central east side of Kauaʻi, stretch along a fairly straight coast, and represent former embayments that have been filled in by sedimentation (Moberly and Chamberlain 1964).



Lānaʻi


Awalua
Polihua Beach
Shipwreck Beach
Kuahua
Kahokunui
Maunalei
Keanapapa Point
Kʻaʻāpa
Honopū Gulch
Nanahoa Island
Lanaʻi City
Halepalaoa Landing
Lōpā Beach
Kaumalapau Harbor
Palikaholo
Naha Beach
Mokunaio Island
Kaunolū Bay
Palaoa Point
Hulopoʻe Bay
Mānele Bay
Puʻu pehe
N
0 km 5 10
0 miles 5

Lāna‘i is a single shield that formed from summit eruptions and along three rift zones between 1.2 and 1.46 Ma; a classic example of a Hawaiian shield with a gently sloping profile. The small sub-circular island has 76 km of general coastline, and a dry climate with minimal stream activity. Similar to Moloka‘i, overgrazing of domestic and feral animals in the 19th century and widespread deforestation on Lāna‘i have drastically changed the stability of the soil. The vegetation has never fully recovered and there is considerable wind erosion on the island (Macdonald et al. 1986).

Three paved roads all lead to the coast from centrally located Lāna‘i City, but a network of four wheel drive roads criss-cross the island from the coast to lookouts atop steep sea cliffs. The edges of the island bear the marks of both wind and wave erosion. Lāna‘i is different from the other Hawaiian islands however, because north and northeast Pacific swells are blocked by the islands of Maui and Moloka‘i, thus protecting Lāna‘i from this source of erosive energy.

Along the northern coastal terrace from Kuahua to Awalua windy conditions have led to the development of a series of sandy beaches and low sand dunes that are fronted offshore by a narrow fringing reef. The beaches, known collectively as Shipwreck Beach, extend along ~13 km of shoreline between Kahokunui beach (to the east) and Polihua Beach (to the west). These beaches are composed mostly of calcareous sand punctuated by



expanses of lithified beachrock. Rocky cobble and boulder deltas occur at the mouths of numerous small streams, which become shallow gulches as they descend from interior Lāna‘i. Wind transported sediments from the island’s northeastern mountains lie in suspension directly offshore, while shallow gulches, between the windward mountains and the coast, provide a route to the sea for terrigenous material during severe rain storms.

The narrow Polihua Beach marks the west end of Shipwreck Beach, and the fringing reef. Polihua is the longest calcareous beach on Lāna‘i, and extends across 2.4 km of the northwest corner of the island.

Between Polihua and Nānāhoa, the coast is rocky and wave eroded with only small offshore coral patches and no calcareous sand. The coast wraps the broad, elongate, westernmost end of the island at Keanapapa Pt. and becomes gradually steeper and more irregular south of the point. Southeast of Keanapapa are numerous sea caves and arches carved into rocky headlands, and offshore rocky islets occur along the





coast. The wave-beaten character of the coast extends the length of the west and southern coast, a signal of the erosive power of southwestern Kona storm waves.

From K'a'ā pa to Nānāhoa, the gently sloping uplands of western Lāna'i are cropped into blunt sea cliffs that periodically release boulders to narrow platforms fronting the headlands below (Fletcher et al. 2002). Offshore of Nānāhoa lies a beautiful assembly of sea stacks, isolated by the retreating coast. The Nānāhoa sea stacks are near the mouth of Honopū Gulch, one of the few stream gulches that have cut through the thickness of the shield down to sea level on the east side, where many others end as hanging valleys.

Between Nānāhoa and Kaumalapau Harbor the sea cliffs reach heights of 105 m and the coast maintains an irregular character to the south, punctuated by low-lying embayments. These east-facing embayments are exposed to the open ocean. However, the north point of the largest embayment, Kaumalapau Bay, is a curved arm that wraps the north portion of the semi-circular bay to point due south at the tip.


Kaumalapau Bay
Reproduced by permission of USGS: Series I-2761

The main Lāna'i shield reveals the mechanism of its landward retreat in large rockslides and slumps along the southwestern coast. This creates great vertical gouges in the Pali wall, producing tall piles of rocky debris that fan out along the shoreline where they are eventually reworked and washed away by

waves (Macdonald et al. 1986; Fletcher et al. 2002).

South of Kaumalapau Harbor the sea cliffs rise up to 300 m above the ocean along the Palikaholo, extending to Mokunaio at the southwest corner of the island near Palaoa Pt. This portion of the wave-truncated shield affords exceptional cross-sectional views of layered pāhoehoe flows, particularly because the arid conditions on the island have prevented extensive stream erosion.

A layer of red colluvium up to 0.5 m thick lies between the lava flows in the cliff along the Palikaholo ~1 km south of Kaumalapau, this is an indication of an erosional period between flows, and is unusual on Lānaʻi (Macdonald et al. 1986). Less then 2 km northwest of Kaunolū, the Kaholo coastal cliffs cut across the southwest rift zone of Lānaʻi. Here, numerous nearly vertical dikes and the cross section of a small shield are exposed in the cliff wall (Macdonald et al. 1986).

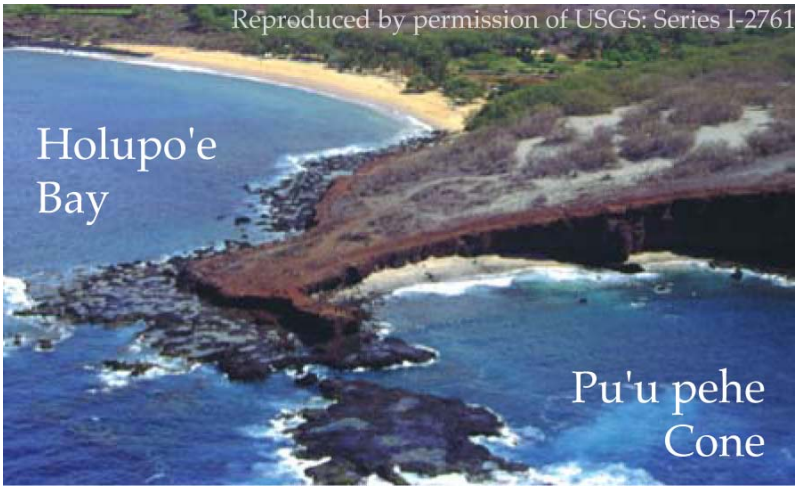
The sea cliffs are reduced to just 30 m in height as they approach



southwest corner of Lānaʻi at Kaunolū Bay on Palaoa Pt. East of Palaoa Pt. the shoreline has a southern exposure and becomes increasingly irregular with small embayments and caves carved into the steep rocky headlands. This wave-eroded shoreline has left numerous isolated rock islets offshore.

The Mānele-Hulopoʻe Marine Life Conservation District lies along the

central south shore where the low-lying embayments at Hulopoʻe and Mānele interrupt a sea cliff coast. Protruding out into the ocean between the bays is Puʻu pehe, an eroded volcanic cinder and spatter cone that has been eroded into a cove at its seaward end. This cove is bordered on the west by a low-lying rocky point that harbors a wide crescent of white sand in its lee, and on the east by a steep cliff with a wave cut terrace running its length along the inside of the cove. The large rock islet isolated offshore of the east point has been separated from the remnant cone by wave erosion.



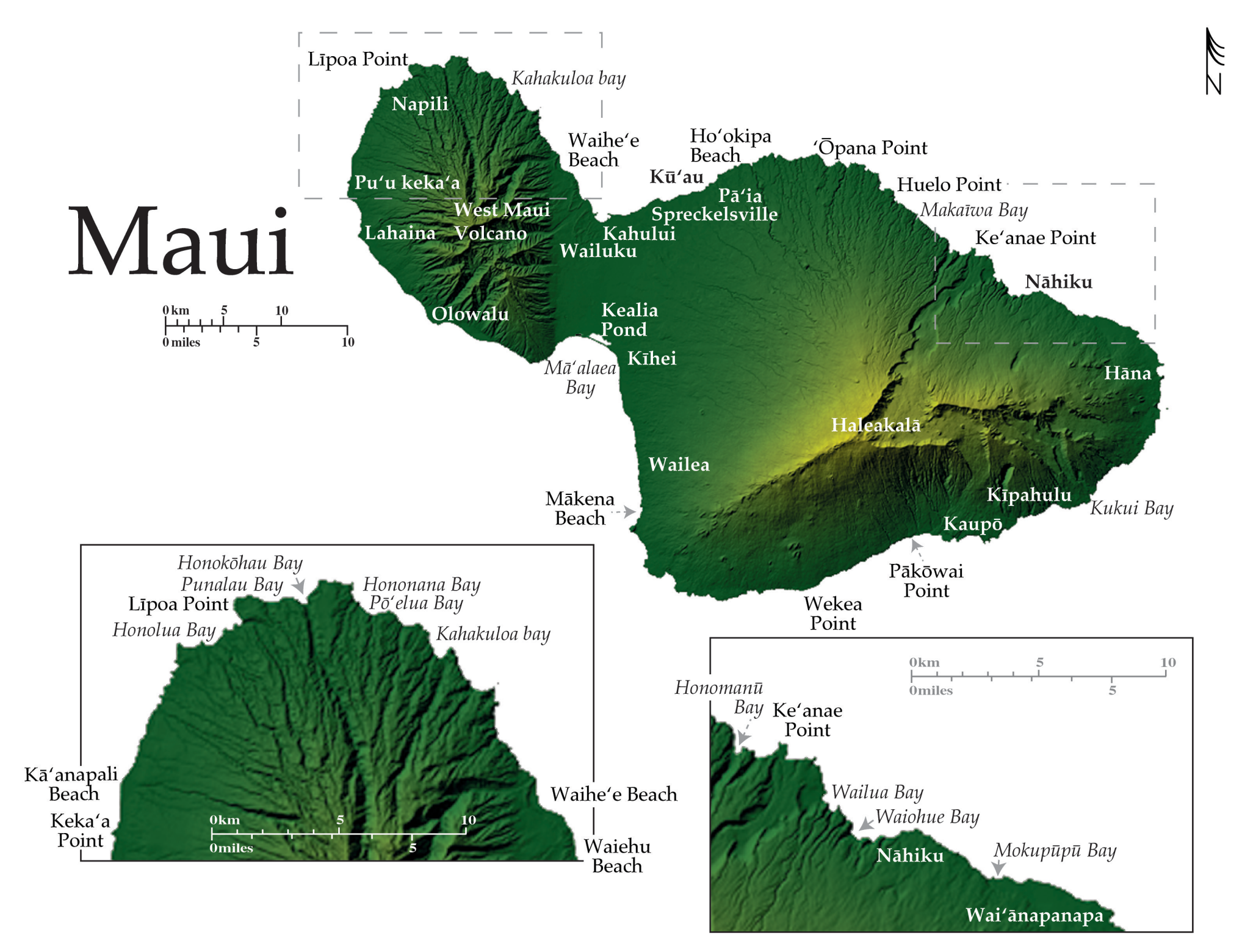
Of additional interest in this area is the famed Hulopoʻe Gravels hypothesized by Moore and Moore (1984) as having been emplaced by a catastrophic tsunami Ca.100, 000 yrs Bp, resulting from a large landslide. Much has been made of this event with deposits and features on the Australian shoreline and elsewhere having been attributed to its occurrence. Rubin et al. (2000) however find coral gravels on Lanaʻi dating from 3 separate interglacial sea level highstands, and the elevations of the Hulopoʻe Gravels to be the result of flexural uplift of the island.

Near Naha and Lōpā southeast Lānaʻi is a narrow low lying coastal terrace fronted nearshore by a narrow and continuous fringing reef. Vegetation overhangs the shoreline here and indicates that the coast is actively retreating.

Beyond the easternmost point near Halepalaoa Landing the coast turns to face northeast and is out of direct exposure to Kona storm waves, allowing the fringing reef to widen offshore while the coast is skirted by broad expanses of alluvium and beaches.

Southeast of Maunalei massive lithified sand dunes extend as far as 3.2 km inland and reach heights of 285 m. Alluvium deltas tend to form at the base of large erosional gulches along this coast, where they lie along the shoreline where they are deposited.




Maui
Līpoa Point
Kahakuloa bay
Napili
Waiheʻe Beach
Hoʻokipa Beach
ʻŌpana Point
Kūʻau
Huelo Point
Pāʻia
Spreckelsville
Makaīwa Bay
Puʻu kekaʻa
West Maui Volcano
Lahaina
Kahului
Wailuku
Keʻanae Point
Nāhiku
0 km 5 10
0 miles 5 10
Olowalu
Kealia Pond
Kīhei
Māʻalaea Bay
Hāna
Haleakalā
Wailea
Mākena Beach
Kīpahulu
Kukui Bay
Kaupō
Pākōwai Point
Wekea Point
Honokōhau Bay
Punalau Bay
Hononana Bay
Pōʻelua Bay
Līpoa Point
Honolua Bay
Kahakuloa bay
Kāʻanapali Beach
Waiheʻe Beach
Kekaʻa Point
0km 5 10
0miles 5
Waiehu Beach
0km 5 10
0miles 5
Honomanū Bay
Keʻanae Point
Wailua Bay
Waiohue Bay
Nāhiku
Mokupūpū Bay
Waiʻānapanapa

The island of Maui is composed of two large volcanoes separated by a low-lying isthmus. The West Maui Volcano (1.6 Ma) at an elevation of 1,764 m lies to the west of the massive Haleakalā Volcano (0.8 Ma) with a summit that reaches to 3,055 m. Maui has 193 km of general coastline that wrap the two main shields and the isthmus. The isthmus was created during the shield building stage of Haleakalā as lava flowed into West Maui and, is bounded by two embayments, one to the north, and one to the south. Although the West Maui Volcano is extinct, Haleakalā is merely dormant having had its most recent rejuvenated eruption just over 200 years ago.

The population on Maui has nearly doubled since 1990 and development of coastal lands has been widespread. The local government has enlisted scientists the University of Hawai‘i in their efforts to gain a clearer understanding of historic and modern shoreline stability particularly with regard to development.

From North Hāna to Ke‘anae, the thickly vegetated countryside along the northeast Maui coast receives an annual average rainfall of 200–300 cm and is fronted by a coastline characterized by steep rocky headlands, low vegetated sea cliffs and shallow sloped embayments. Many of the bays in this area such as Mokupūpū, Waiohue, and Wailua bays, are bordered by lava points


Nāhiku shoreline
Reproduced by permission of USGS: Series I-2761

bounding pocket beaches composed of shingle and basalt pebbles, and boulders. This terrigenous material has been deposited by streams flowing from the heights of Haleakalā. The eastern portion of the north shore has no protective fringing reef and the sea cliff shoreline and sea stacks nearshore are testimony to the erosive powers of the northeastern trade winds and waves that impact the coast.

As recently as 1,200–1,500 years ago, rejuvenated lava of the Hāna Volcanic Series flooded the deep erosional Ke‘anae Valley on the northeast side of Haleakalā, creating a wide, shallow, and jagged lava fan that reaches 1.5 km into the ocean. West of Ke‘anae the sea cliff coastline extends, giving way to only a few narrow stretches of boulder beach backed by deep thickly vegetated valleys like those found within the embayments at Honomanū and Makaīwa.



Maui has become well known among extreme sport enthusiasts for giant waves on the north shore that break over offshore shoals during periods of exceptionally high surf. A short four-wheel drive through the pineapple fields at the base of Peahi Gulch, west of Ke‘anae Pt., brings spectators to the high, rugged, and unprotected muddy cliffs overlooking the facous surf break called “Jaws”, or locally “Peahi”. Here expert tow-in surfers and windsurfers ride the

12 to 21 m faces of waves moving at speeds up to ~48 km/hr, frequently with film crews capturing their feats from helicopters overhead. Large swells are required to cause waves to break over the deep reef in the small steep-sided bays of this area.



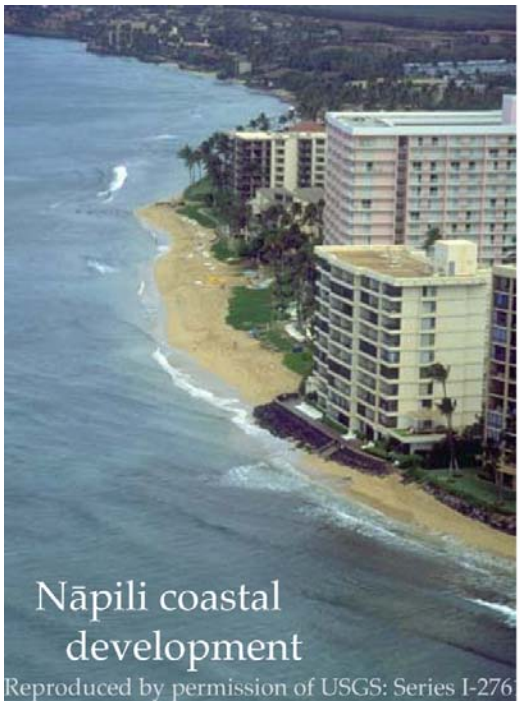
The northwest East Maui lowlands are relatively dry with annual rainfall between 75-150 cm. The lowlands are occupied by extensive agricultural, public and residential development. The coastal town of Pāʻia, the neighborhoods of Kūʻau and Spreckelsville, and the Kahului Airport line the broad sandy embayment of the northeast side of the north Maui isthmus. This area was characterized by extensive low sand dunes during the dynamic changes in relative sea level of the Pleistocene Epoch. Much of the shoreline in this area now contains long beaches of calcareous sand mixed with coral rubble and basalt rock. Broad patches of lithified beachrock lie at the waters edge, while a broad fringing reef offshore provides moderate protection to the coast from the direct impact of North



Pacific winter surf. These beaches are interrupted periodically by groins and other engineered structures erected *ad hoc* to mitigate the loss of coastal properties.

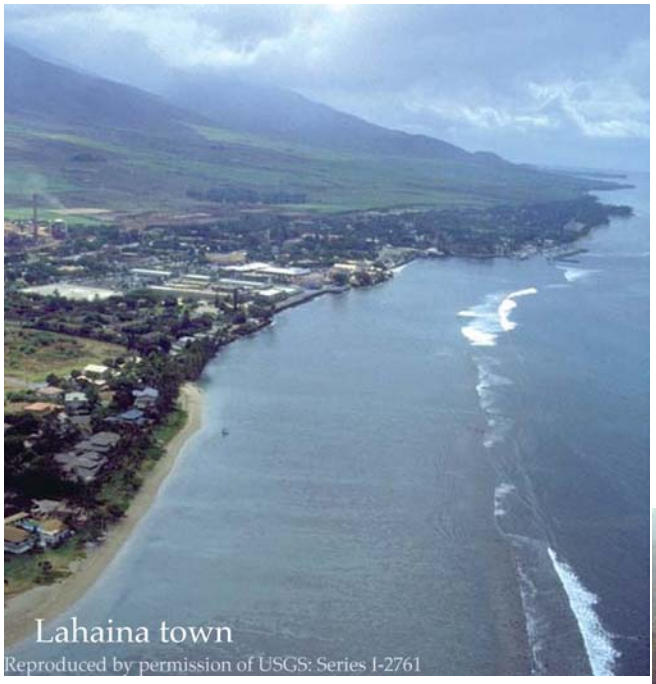
The central north side of the isthmus, at Kahululi and Wailuku, has been developed as a hub of industrial activity and the coast is primarily a commercial deep-draft harbor and heavily constructed shoreline. Development extends for 4 km northeast along the low sloping lands of the West Maui Volcano. The narrow shoreline is largely backed by seawalls, residential neighborhoods, and in the case of Waiheʻe and Waiehu Beach Parks, a golf course.

West of Waiheʻe the coast is narrow and undeveloped, with v-shaped valleys and vegetated gulches carved by surface runoff channeling to the sea. North Pacific waves have cut the shoreline into steep rugged sea cliffs that are skirted by boulders and fluvial deposits. Six major bays along the coast are widely enjoyed by surfers and are bordered by sea cliffs and lava points: Kahakuloa, Pōʻelua, Hononana, Honokōhau, Punalau, and Honolua bays hold pocket sandy beaches in the summer that may erode to reveal boulders in the winter. Access to this region is difficult as no paved road extends the entire length of the coastline.


Nāpili coastal development
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The west facing Nāpili-Kāʻanapali coast of West Maui receives 40–75 cm of rain each year and has a shallow slope that is traversed periodically by streams and surface runoff. Many beaches here are

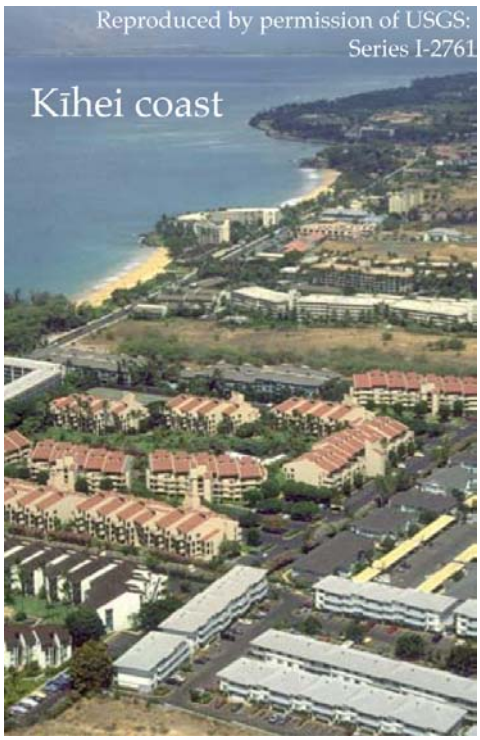
backed directly by seawalls and revetments, built to protect extensive tourist facilities and commercial development from erosion. Because of chronic moderate erosion there is a significant problem with beach loss and narrowing along the hardened coast. The coastline alternates between rocky headlands, and narrow calcareous sandy pocket beaches and is protected from North Pacific swell along its length by offshore fringing reef. A point of geologic interest here is the black volcanic cinder cone Puʻu kekaʻa (Black Rock) that bisects Kāʻanapali Beach into two distinct segments.


Lahaina town
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Along the southwest facing shore of West Maui heavy development continues at the historic port town and tourist destination, Lahaina. Here the shoreline is rocky with only narrow sand pockets, and in many areas, the ocean laps against the island at seawalls and revetments where beaches once lay. Nearshore portions of wide fringing reef are revealed at low tide and buffer the coast from south swell and Kona storms. The Lahaina-Olowalu coast, along the southern embayment of the Maui


Olowalu coast
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isthmus, is lined by long stretches of alternating calcareous sand and basalt pebble beaches, backed by narrow sparsely vegetated dunes and a busy highway. This coast frequently experiences high wind speeds because of trade winds that are channeled between the prominent east and west volcanoes across the isthmus. The south coast of the Maui Isthmus contains eroded soil bluffs behind the M'a'ā laea recreational boat harbor on the west end. To the east, the coast transitions to a sandy shoreline, fronting the Keālia Wildlife Refuge in the center of the isthmus.

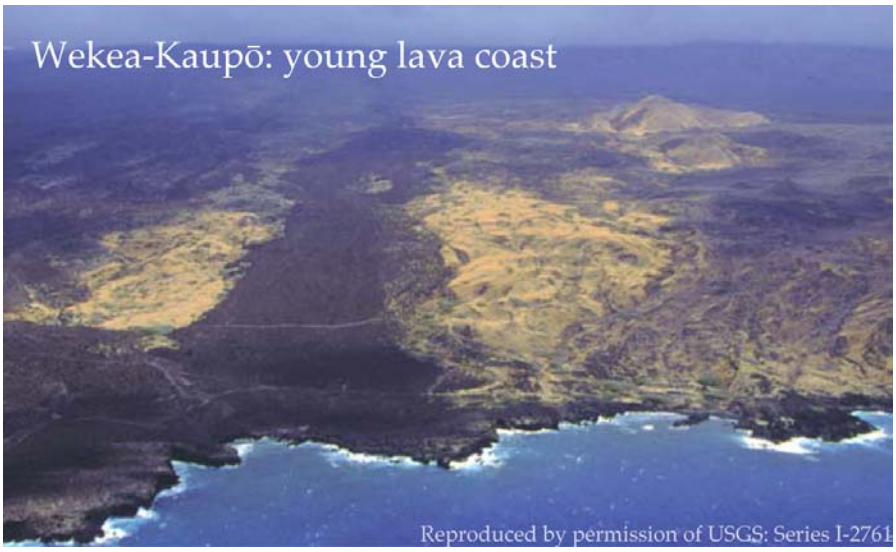


East of the isthmus the shallow sloped coast of Haleakalā faces due west and is heavily developed with tourist facilities at Kīhei and Wailea. Here seawalls and hotel property back long stretches of calcareous sandy beach of varying widths. This coast receives less than 40 cm of rain each year and although moderately protected by fringing reef much of the shoreline is eroded to beachrock, shingle, and cobble by southwestern Kona storm waves.

South of luxury developments at Wailea the west facing coast of Haleakalā is streaked by the most recent lava flows on Maui (circa 1790). Vents at 465 and 170 m above current sea level erupted covering 5.7 km² of the southwest side of the mountain with lava. A cone from this episode, 109 m high, lies on the coast and separates two wide calcareous beaches: Big Beach and Little Beach collectively known as Mākena Beach. Big Beach is an important local and

tourist recreation area stretching over 1000 m, and is ~20 m wide and backed by a sand floored forest of Kiawe trees.

Lava from rejuvenated eruptions cover the south side of the Haleakalā shield along the Wekea-Kaupō coast, and the immense arid mountainside is largely undeveloped from the coast to the crater at the summit over 3000 m above. The mountainside is minimally eroded by fresh water and the terrain has retained its sharp and jagged surface along the more than 50 km of dry southern coast. At the shoreline shallow sloped lava points and steep rocky headlands have been eroded by waves resulting in a natural sea arch near Pakowai and weathered rocky islets and sea stacks offshore.

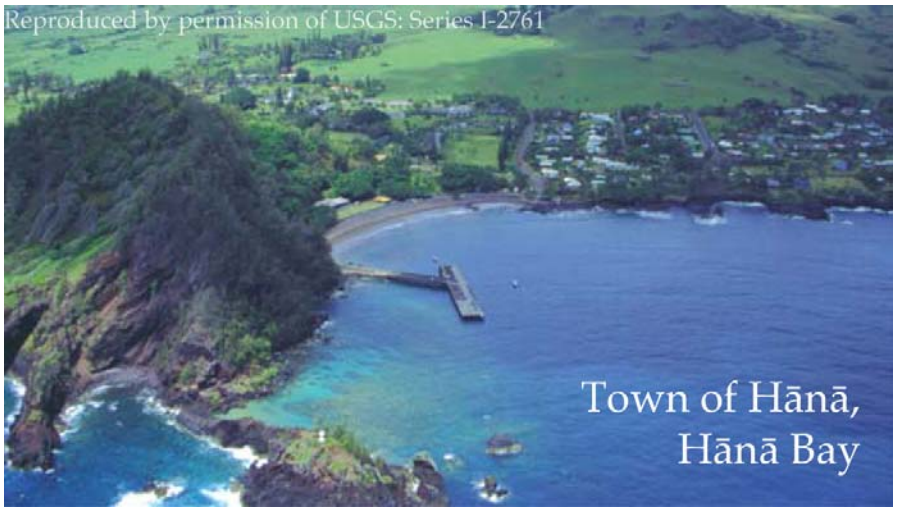


Around the southeast end of the island the Kīpahulu coast is regularly inundated by heavy surf churned and refracted around the coast to the north by the trade winds. A variable

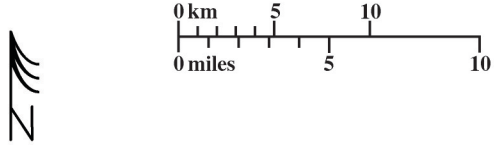


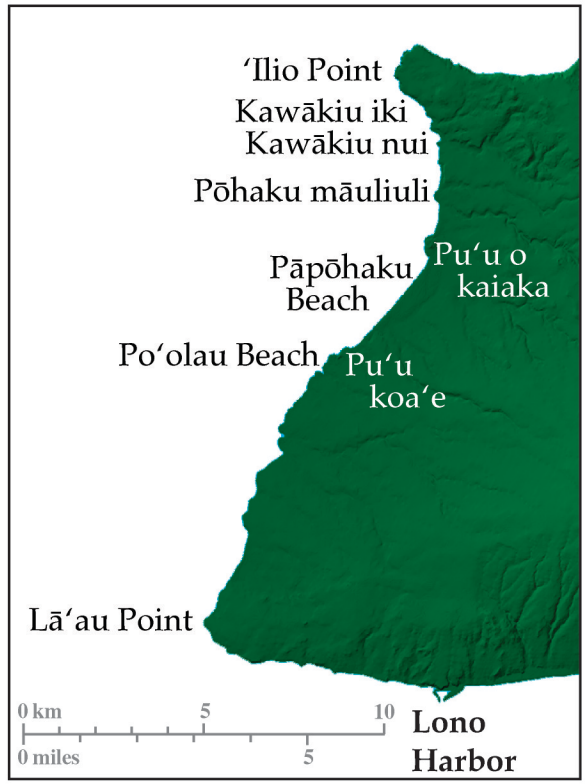
morphology of steep rocky headlands and shallow sloped embayments characterizes the shoreline. The mountainside along the southeast and east side of Haleakalā transitions rapidly from arid and moderately sloped shorelines to lush steep cliffs in a few shallow landings to the sea.

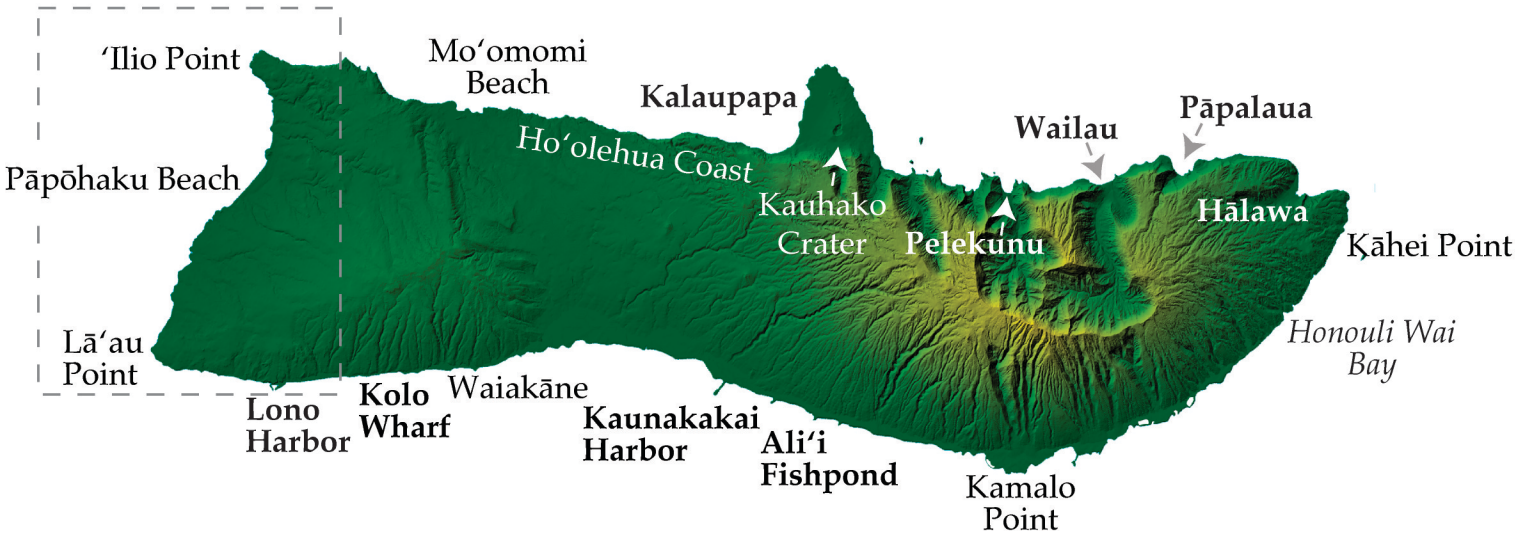
The Hāna coast contains some of the most beautiful and scenic lands on Maui with steep rocky headlands, shallow sloped bays, and cinder cones of rejuvenated volcanism located sporadically along the coast with sea stacks and small rocky islands lying offshore. Wide summer pocket beaches of white sand are tucked into the lee of rocky points, high sea cliffs and cinder cones. During the winter this shoreline experiences considerable erosion, and black sands, products of these erosive events, lie along the coast under lava cliffs in areas such as Wai'nāpanapa.



Molokaʻi


0 km 5 10
0 miles 5 10


ʻIlio Point
Kawākiu iki
Kawākiu nui
Pōhaku māuliuli
Pāpōhaku Beach
Puʻu o kaiaka
Poʻolau Beach
Puʻu koaʻe
Lāʻau Point
0 km 5 10
0 miles 5
Lono Harbor


ʻIlio Point
Moʻomomi Beach
Kalaupapa
Hoʻolehua Coast
Pāpōhaku Beach
Kauhako Crater
Pelekūnu
Wailau
Pāpalaua
Hālawa
Kāhei Point
Honouli Wai Bay
Lāʻau Point
Lono Harbor
Kolo Wharf
Waiakāne
Kaunakakai Harbor
Aliʻi Fishpond
Kamalo Point

The island of Molokaʻi extends ~62 km east to west and lies ~20 km north of Lānaʻi. The island was formed by two main shield volcanoes. Lavas of the younger East Molokaʻi (1.52 my in age) flowed into the eastern flanks of preexisting West Molokaʻi (1.89 my in age), creating a wide isthmus and producing the elongate island with 142 km of general coastline.

Although close neighbors, the two main shields are dissimilar climatically, and thus morphologically. Maunaloa (420 m), the West Molokaʻi volcano, is a dry flat-topped shield partly protected from east and northeast trade winds by East Molokaʻi (1,514 m). Maunaloa receives no more than 50 cm of rain annually. Without the orographic ability to catch clouds, West Molokaʻi experiences little rainfall. However, due to overgrazing, deforestation, and removal of native plants, West Molokaʻi is susceptible to massive erosional events related to heavy rainfall, that have carved deep gullies into the island. The island's rain falls primarily on East Molokaʻi, up to 400 cm annually at the summit and 200 cm annually along the north coast. The shield has been cut into deep spectacular valleys and high steep ridges that are lush and vibrantly green.

Most of the north coast of East Molokaʻi, from Hālawa to Kalaupapa, has been sculpted in to sea cliffs (600 – 800 m) that are frequently awash with waves from powerful North Pacific swells. These cliffs are bisected by prominent coastal



Wailau coast

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ridges and valleys such as Hālawa, Pāpalaua, Wailau, and, Pelekunu, that have been carved by severe stream erosion. Substantial low-lying terrain is found on valley floors and at the boulder beaches where the valleys meet the sea, accreting dark detrital sand in the summer when North Pacific swell is at a minimum.


Pelekunu Valley
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A flight over Moloka‘i reveals Kalaupapa Peninsula, a broad coastal plain projecting out from the base of the sea cliffs of northern East Moloka‘i. The peninsula is a basaltic shield of rejuvenated volcanism that erupted from Kauhako Crater centrally located on the peninsusula. The collapsed lava tube through which Kalaupapa’s lavas flowed is still discernable and extends north at the surface from the crater to the sea. The crater is over 0.5 km in diameter and filled with a pool of brackish water more then 135 m deep. Numerous sea stacks and rock islets lie off the eastern shore of Kalaupapa. These remnants are composed of the same thinly layered flows that make up East Moloka‘i, and have been isolated by the retreating north coast. The east (windward) shore of Kalaupapa extends as a nearly continuous low sea cliff and remains void of sand until the northeast end of the peninsula where it grades to a mixed beach of white sand and coral rubble (Clark 1989).

The northwest edge of Kalaupapa is a graded terrace of stream laid conglomerate lying 30 m above present sea level that was formed at a higher

stand of the sea (Macdonald et al. 1986). Narrow storm beaches at the base of northwest Kalaupapa are maintained by high surf, which transports sand over tide pools and rocky shelves at the shoreline. The western nape of Kalaupapa is generally lined with white sand, increasing in width closer to the main island and transitioning into a long and wide detrital beach where the island and peninsula meet.

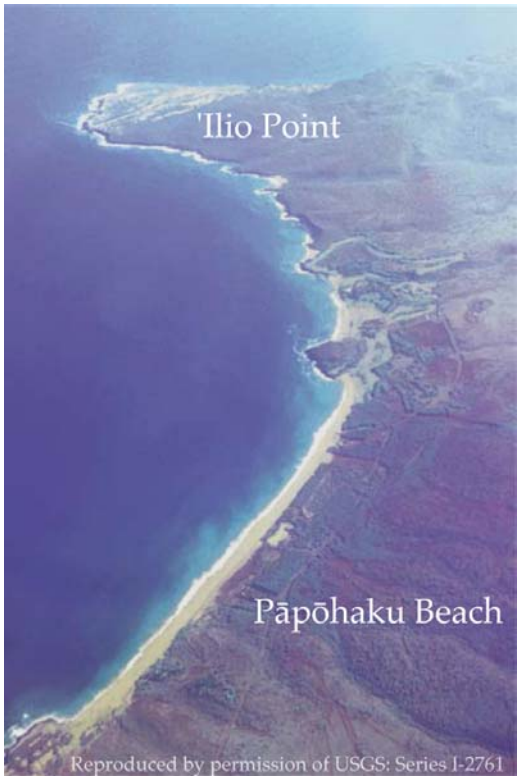

Ho'olehua coastline
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West of Kalaupapa along the Ho‘olehua coastline, the sea cliffs of East Moloka‘i lower and the rocky coast is exposed to consistent trade winds between 16 and 30 km/h, creating rough offshore conditions and inhibiting any extensive development of coral reef. Another result of intense and consistent winds, over long durations, is the dry sandy shoreline of west Moloka‘i, extending from Mo‘omomi at the east to ‘Ilio Pt. in the west.

Mo‘omomi is an area of active dune formation where unconsolidated sand lies anchored by modest vegetation atop older Pleistocene dunes now cemented to eolianite. Moderately steep headlands, less than 30 m high, line the windy northwest Moloka‘i coast from the western edge of the Mo‘omomi dune area to ‘Ilio Pt. Only a few calcareous beaches backed by vegetated dunes exist at the shoreline. In places the headlands have been cut into gulches by flash

flooding, however constant winds and the low elevation in this area keep this side of Molokaʻi generally dry.

An extensive sandy dune complex occupies the northwest corner of Molokaʻi, inland of Moʻomomi Beach. This Desert Strip contains an abundance of both unconsolidated calcareous sand and carbonate eolianite that forms a belt of dunes extending up to 18 m high, 0.8 km wide and which reaches over 6 km inland from the coast (Macdonald et al. 1986). Active dunes accrue sand from older eroding lithified dunes in the area that have been dated to the late last interglacial (Hearty et al. 2000) ; however most of the loose sand is transported by wind from the northwestern shores (Clark 1989; Macdonald et al. 1986).



The west coast from ʻIlio Pt. to Lāʻau Pt. spans the distance between the northwest and southwest rift zones and is rocky terrain with wave cut headlands and terraces interspersed with long sections of embayed calcareous beach at the shoreline. South of ʻIlio Pt. the coast curves gently inland to small rocky embayments at Kawākiu iki and Kawākiu nui, Pōkaku māuliuli, Puʻu o kaiaka, that protect small calcareous pocket beaches. Landward of the embayments are intermittent stream gulches that feed small wetlands in the vicinity.

Further south is the largely unvisited calcareous Pāpōhaku Beach.

Stretching over 3 km of the pristine western shoreline, the beach averages almost 100 m wide is backed by a cinder cone headland to the north, and an eolianite and lava headland to the south. The ample beach at Pāpōhaku, and the large sand field just offshore, exist here despite little significant development of coral reefs along the west coast (Fletcher et al. 2002). Pāpōhaku has been mined in the past as a source of sand.

Rocky headlands such as Pu'u koa'e lie to the south of Pāpōhaku. These headlands and the small rocky islets off the west coast indicate the erosive power of the heavy surf that pounds this side of Moloka'i in the winter and spring.

Lā'au Pt. is located at the southwestern corner of the island and extends underwater for 65 km as the broad Penguin Bank shoal. The shoal is probably a separate shield that grew along the trend of the southwest rift zone. Although the shoal was cut by wave erosion, it lies 54 m below sea level, indicating that it was at or near the surface at a lower stand of the sea (Macdonald et al. 1986).


Lono Harbor
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The arid south shore of west Moloka'i, from Lā'au Pt. to the west border of Pākanaka Fishpond, has a gentle slope and is shallow and rocky between the shoreline and offshore reef. Broad sections of fringing reef extend from either side of Lono Harbor, widening toward the east toward Kolo Wharf. The fringing reef on the south shore of Moloka'i is the largest in the main

Hawaiian islands, extending ~53 km along the coast.

Mangroves were introduced to this coast to head off coastal erosion, but have instead intensified the problem of terrigenous mud deposition forming extensive mud flats. Mangroves, and the inland wetlands they encourage, span much of the south coast on west Moloka'i. Ultimately, the result of sedimentation and mangrove proliferation is the formation of a prograding shoreline and the development of interior wetlands that extend east on the southern Moloka'i coast, toward Kaunakakai Harbor (Fletcher et al. 2002).


Silted waters off Waiakāne
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Coastal erosion affects long sections of the south Moloka'i shoreline as indicated by scarped dunes, fallen trees, and extensive outcrops of beachrock, as seen at Kolo Wharf. Widespread upland erosion on west Moloka'i has developed as a result of poor land management practices. Over grazing, deforestation, and invasion by alien species has resulted in sedimentation of nearshore waters and the seaward migration of a muddy coast onto live reef.

The coastal highway that runs along south Moloka'i is built on a low terrace formed by the Kapapa high stand of the sea ca. 3000 yrs BP.

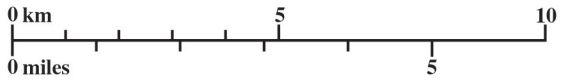
Almost 50 ancient Hawaiian fish ponds were built on south Moloka'i between Kolo and Honouli Wai on the east side of the island, however most have

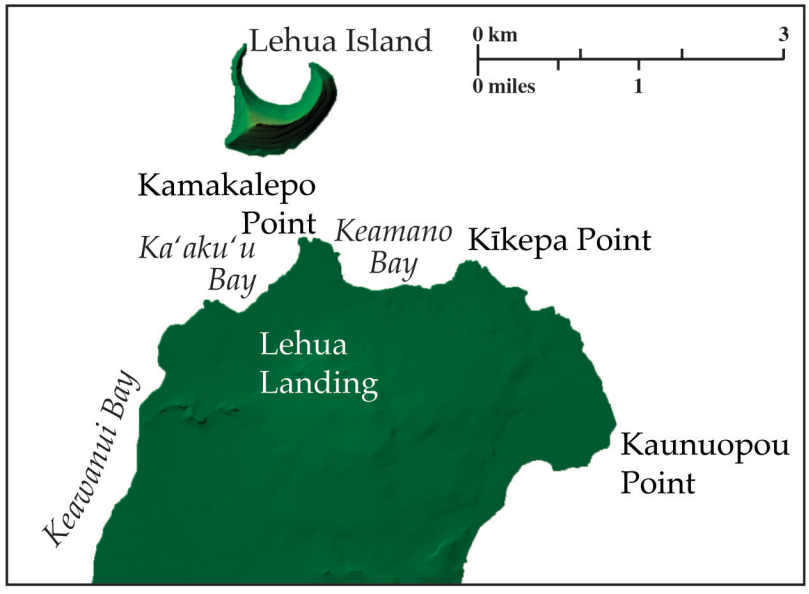
been infilled by muddy alluvium and populated by the troublesome mangroves. Along the southeast facing coast of Moloka‘i, the shore is skirted by narrow sand and detrital beaches that are fronted by shallow waters with rocky nearshore bottoms leading out to shallow offshore reef.

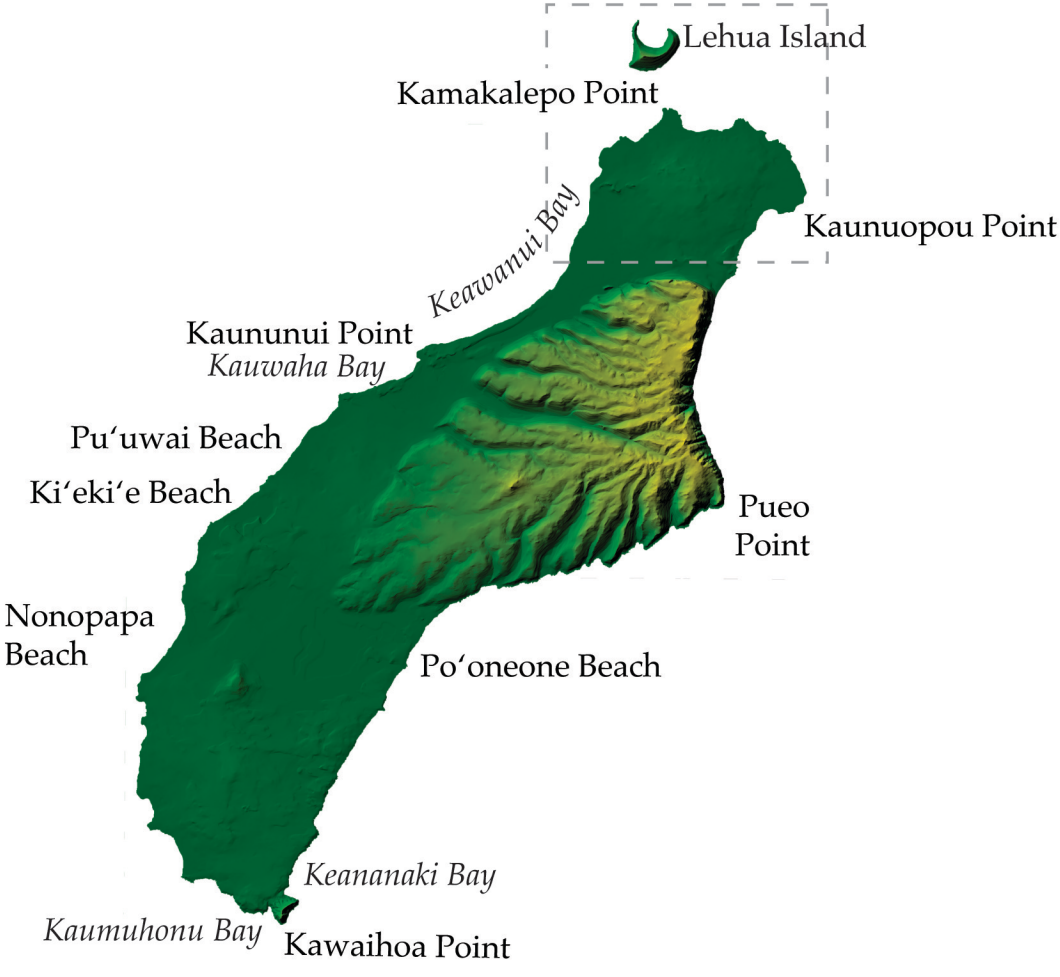

Kamalō coastal plain
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Mangrove forests have also invaded the shallow shoreline east of Kaunakakai. From Kawela to Kamalō, to Pūko‘o, the coast is shallow sloped with shallow offshore waters. Waters between the shoreline and the fringinging reef offshore are frequently muddy with sediment and silt washed down from the island’s interior.

Ni‘ihau


0 km
5
10
0 miles
5


Lehua Island
0 km
3
0 miles
1
Kamakalepo Point
Ka‘aku‘u Bay
Keamano Bay
Kīkepa Point
Lehua Landing
Keawanui Bay
Kaunuopou Point


Lehua Island
Kamakalepo Point
Keawanui Bay
Kaunuopou Point
Kaununui Point
Kauwaha Bay
Pu‘uwai Beach
Ki‘eki‘e Beach
Pueo Point
Nonopapa Beach
Po‘oneone Beach
Keananaki Bay
Kaumuhonu Bay
Kawaihoa Point

Since 1864 the island of Niʻihau has been held and maintained by the Robinson family, who operate a modest but productive ranch on the island. Except for helicopter tours, with limited and remote destinations such as, Kamakalepo Pt. on the north side, Nonopapa on the west side, and Keanahaki on the south side, Niʻihau is not open to the public. The Robinson's closed-door policy has served to preserve the native Hawaiian lifestyle on the island where roughly 160 residents live and work without regular contact with the modern world and, where Hawaiian is the primary language spoken. Because of limited access, no significant geologic study of the island has been undertaken.

Niʻihau is a small elongate island (29 x 10 km) that stretches from southwest to northeast containing 145 km of general coastline. Niʻihau lies at the far northwest end of the main Hawaiian islands and is the low lying subaerial remains of a volcanic shield built ~4.89 Ma (Clague and Dalrymple 1987).

The summit of the volcano was originally northeast of the present day island, but was subsequently removed, along with much of the northeast side of the island, by erosion or possibly, downfaulting (Clague and Dalrymple 1987). The basaltic remains of the western outer slope of the shield's caldera make up a significant proportion of the north portion of the east coast of modern Niʻihau.

A large tuff island less than 2 km off the north coast is visible from the northwest corner of Niʻihau, at Lehua landing. The horseshoe shaped Lehua Island is the product of rejuvenated volcanism and has been sculpted by marine erosion. The steep sea cliff on the south side of this relatively small island has been notched with sea caves at the waters edge. The island tapers to low-lying points that border a wide mouthed bay that opens to the north. Lehua Island functions as a part of the Hawaiʻi State Seabird Sanctuary.

The north coast of Niʻihau, from Kaunuopou Pt. to Kīkepa Pt., is composed of low volcanic cliffs that have been weathered and shaped by marine erosion. The shoreline is rocky and lined with boulder beaches and a few small pockets of calcareous sand that are tucked into the irregularities at the base of the cliffs.

The broad Keamano embayment lies west of Kīkepa Pt., opening to the north with a crescent of calcareous sand over 1 km long along the shoreline. Keamanu marks the beginning of broadly embayed sandy beach systems that dominate the northwestern coast. These shorelines, including Kaʻakuʻu, Keawanui, and Kauwaha bays, are separated by rocky points and backed by extensive dune systems that reach up to 30 m in height.

The southwest portion of Keawanui Bay holds almost 5 km of uninterrupted sandy beach at the shoreline. The broad dune system along the north coast extends almost a kilometer inland. These largely unconsolidated coastal dunes are vegetated with endemic Hawaiian coastal plants and are mobilized along the coast by prevailing wind and sea conditions.

Powerful north swells reach this coast and are evidenced by large blocks and slabs of beachrock that lie broken along the shoreline of Keawanui Bay. However, the sand reservoirs and dunes of the north coast are extensive and they guard the coastal lands from erosion and long-term coastal retreat, despite the pounding of onshore surf. Thus, the dunes play an important role in the maintenance of this small, fully exposed island (Clark 1990).

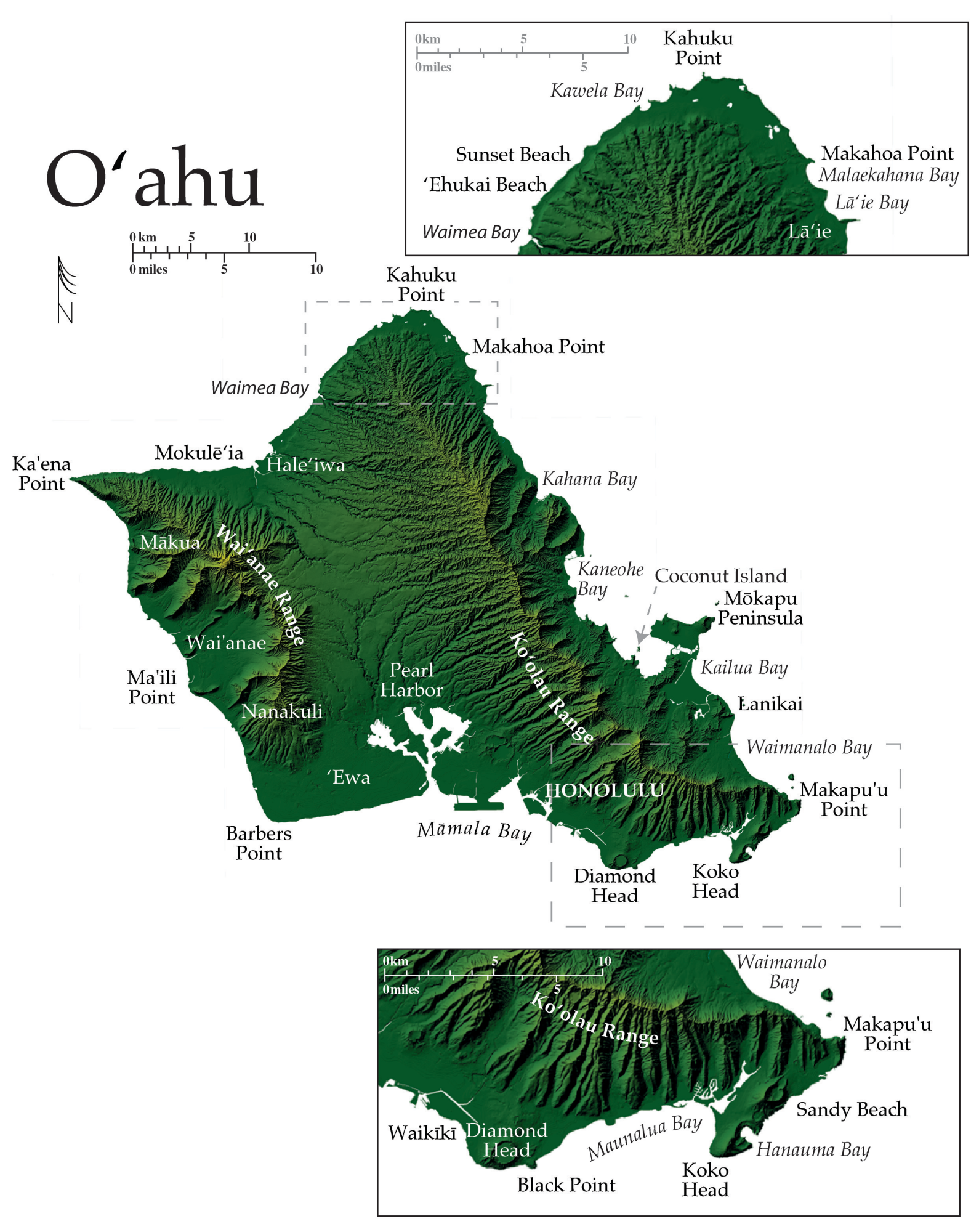
The central-west shores of the island, from Kaununui Pt. to Nonopapa Beach, are very sandy, however the beaches here; Puʻuwai, Kiʻekiʻe, and Nonopapa, are generally narrower than the beaches to the north, varying with

the season and attaining their greatest widths in the summer. These beaches are some of the longest on the island; with Pu‘uwai stretching over 3 km, and Ki‘eki‘e over 2 km. Low vegetated dunes and a low-sloping interior back this section of coast.

The shoreline becomes increasingly rocky south of Nonopapa, transitioning to low sea cliffs that wrap the southern tip of the island at Kawaihoa Pt., a large tuff cone that stands almost 170 m high. Basalt and limestone inclusions incorporated into the cemented ash of Kawaihoa, are pieces of the shoreline and nearshore coral reef that were ripped up during the explosive formation of the cone. Kawaihoa forms a broad headland with embayments on both the leeward and windward sides. On the leeward side the deeper of the two bays, Kaumuhonu Bay is lined at the shoreline with a beach that sits atop a wave cut bench. Keananaki Bay on the eastern side is shallower and lined with large pockets of sand fronted by a rocky shelf (Clark 1990).

The east side of Ni’ihau is thoroughly impacted by the northeast trade winds that together with associated waves and currents, drive natural and anthropogenic debris, such as fishing floats and drift wood, onto the shore in great quantities.

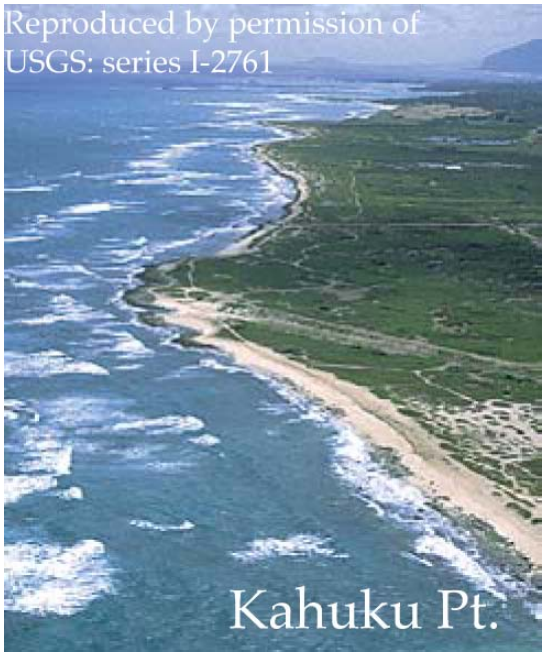
Less than 10 km north of Kawaihoa Pt. lays the long wide sandy shoreline at Po’ooneone, which runs nearly 4 km to the base of basalt sea cliffs to the north. The cliffs, reaching up to 360 m in height, and defining the shoreline for over 15 km of the central eastern coastline, are the remains of the old Ni‘ihau shield. Numerous dikes can be viewed in the shield, particularly in the walls of valleys cut deep into the southeastern exposure of the coast (Clague and Dalrymple 1987).


O‘ahu
0 km 5 10
0 miles 5 10
N
0km 5 10
0miles 5
Kahuku Point
Kawela Bay
Sunset Beach
‘Ehukai Beach
Waimea Bay
Makahoa Point
Malaekahana Bay
Lā‘ie Bay
Lā‘ie
Kahuku Point
Makahoa Point
Waimea Bay
Mokulē‘ia
Hale‘iwa
Ka'ena Point
Kahana Bay
Mākua
Wai'anae Range
Kaneohe Bay
Coconut Island
Mōkapu Peninsula
Wai'anae
Ko‘olau Range
Kailua Bay
Pearl Harbor
Ma'ili Point
Nanakuli
Ła‘nikai
Waimanalo Bay
‘Ewa
HONOLULU
Makapu'u Point
Barbers Point
Māmala Bay
Diamond Head
Koko Head
0km 5 10
0miles 5
Waimanalo Bay
Ko‘olau Range
Makapu'u Point
Sandy Beach
Waikīkī
Diamond Head
Maunalua Bay
Hanauma Bay
Koko Head
Black Point

O‘ahu is the third largest Hawaiian island with 180 km of general coastline that contours a highly irregular shape that was greatly influenced by two massive landslides, that removed ~1/3 of the northeastern portion of the island and aproximately 1/2 of the western side. Today, the shape of O‘ahu is constrained by two great mountain ranges that are the eroded remnants of two separate shields truncated by the prodigious slides.

The Ko‘olau Range (2.7 my in age) runs up the northeast side of the island, perpendicular to the trade winds, whereas the older Wai‘anae Range (3.9 my in age) extends along the west side. Moisture rich trade winds are typically pushed across the broad side of the Ko‘olaus, maintaining lush vegetation that reaches from the mountains to the coast. In contrast, the Wai‘anae Range on the west side is dry, receiving little of the moisture carried by the trade winds.

O‘ahu is the most densely populated Hawaiian island, home to almost 900,000 of the total 1,200,000 residents in the State. The combination of a dense population, government, and an industry dedicated to tourism, results in heavy use of the islands shorelines.



Kahuku Pt. at the northeastern tip of the island is a low coastal terrace backed by extensive wetland areas that contain: the James Campbell National Wild Life Refuge and large shrimp aquaculture ponds. Rocky limestone cliffs surround embayments on the west side of Kahuku Pt., while relict and modern dune fields occupy much of the

seaward edge of the point. Kahuku Pt. and Makahoa Pt., to the east, are examples of lithified eolianites that have been shaped by chemical weathering, intertidal boierosion, and the northeast trade winds to which they are fully exposed.

The northwest coast of O'ahu extends from Kahuku Pt. to Hale'iwa, and is characterized by massive winter surf, long sandy beaches, rocky points, and patches of exposed beack rock. The beach rock is particularly exposed in the winter, when foreshore slopes steepen, and large quantities of sand are moved by high surf from the waters edge toward the back of the beach. Sand at the shoreline is mostly coarse grained and calcareous, a signature of the high energy waves that impact this coast in the winter.



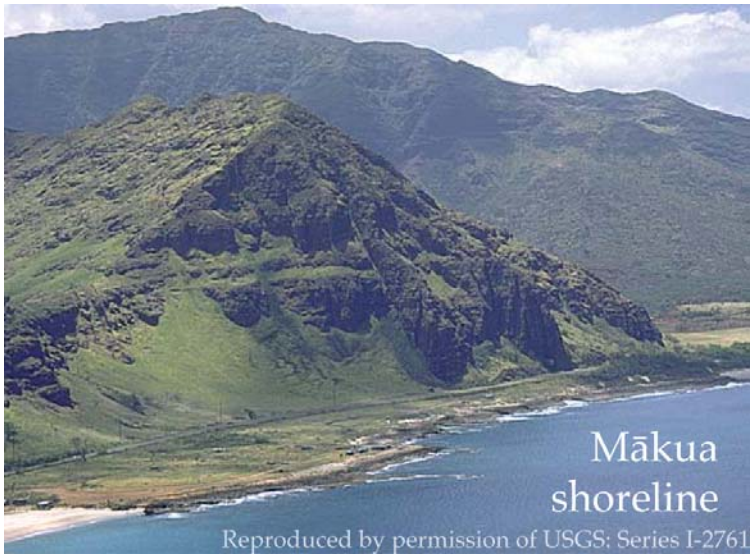
Many of Hawai'i's renowned surf breaks exist on the northwest coast between Kawela Bay and Hale'iwa, where wave heights can reach up to 10-15 m. On any given winter day spectators along the beaches at Sunset Beach, 'Ehukai Beach (Pipline), Banzai Beach, and Waimea Bay, will undoubtedly be impressed by the powerful surf and those that venture to ride it. In contrast,



summer conditions on these same beaches are placid, and the steep winter shorelines replaced by flat wide beaches.

The Mokulēʻia shoreline extends west from Haleʻiwa toward Kaʻena Pt. at the westernmost corner of the island. This low lying coastal terrace faces due north with consistent trade winds blowing across it to the base of the northern Waiʻanae Range. Nearly the entire coastline from Mokulēʻia to Kaʻena Pt. is fronted by broad wave-cut platforms of older limestone with small sandy beaches and vegetated dunes occurring in gaps along the shoreline.

The coastal slope increases in steepness as the Mokulēʻia shoreline approaches Kaʻena Pt. The point is composed largely of fossiliferous coral conglomerate with loose coral and basalt cobbles up to ~10 m above sea level, fronted by a dune field. The road that once ran around Kaʻena Pt., to Mākua on the western shore of Oʻahu, was destroyed years ago by high surf and chronic erosion.



Large surf and windy conditions prevail along the west side where sandy beach embayments and beautiful basaltic headlands characterize the coast. Reef limestone ~ 30 and 6 m above modern sea level is found near Waiʻanae and Nānākuli along this coast indicating higher past stands of the sea associated with interglacial periods ca. 500,000 yrs and 125,000 yrs BP (Jones 1993).

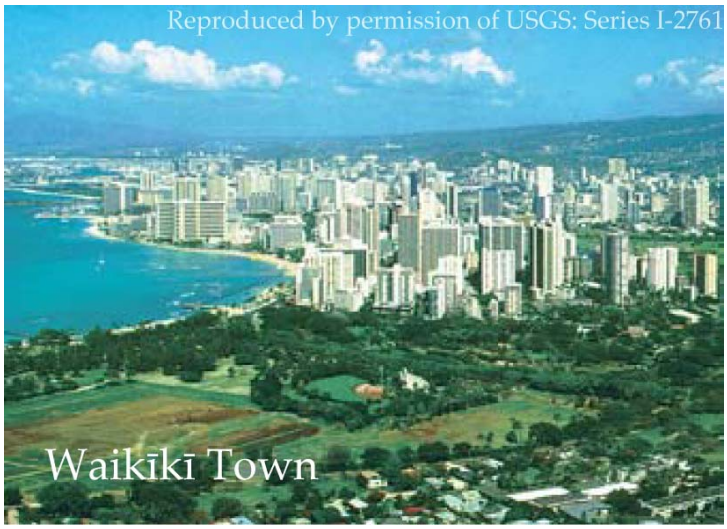
The south shore of O'ahu is almost completely developed from the oil refineries at Barbers Pt. to the dense neighborhood developments at Hawai'i Kai and Portlock. Much of the shoreline is artificially hardened to protect the densely packed communities that lie directly inland, where tourism and local businesses thrive in an ideal tropical climate



The Pearl Harbor embayment, along the south coast, formed as the island sank ~360 m toward the end of the main shield building phase, drowning the river valleys that drain central O'ahu. Pearl Harbor contains almost 50 km of shoreline backed by extensive wetlands through which highly sedimented waters enter the harbor. The coastal plains to the west and east of Pearl Harbor, 'Ewa and Honolulu, lie atop a broad coral reef platform from the late Pleistocene last interglacial that developed during interglacial periods of warmer waters and higher relative sea level.

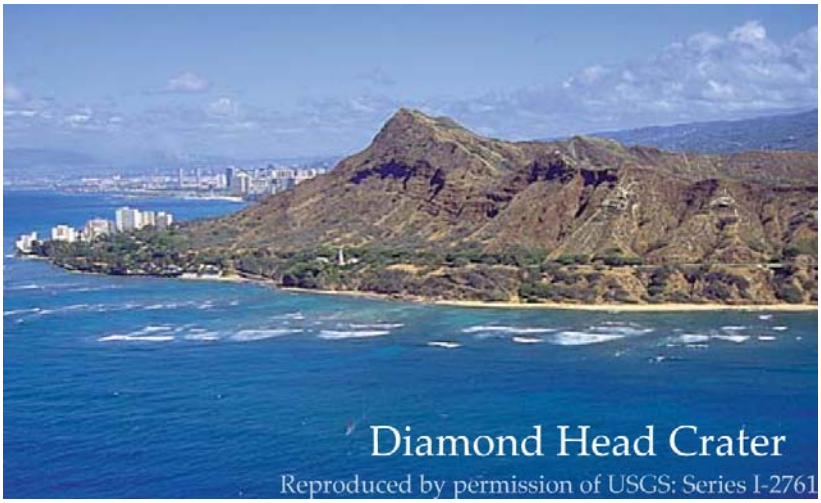
Most of the year, south shore surf breaks fronting Honolulu and Waikīkī are crowded with local and tourist enthusiasts, taking advantage of long period surf formed by storms in the southern hemisphere.

Waikīkī, perhaps one of the best-known shorelines in the nation, and a center of tourist activity, lies at the eastern end of Honolulu. Waikīkī was, until



the beginning of the 20th century, a wetland and marsh holding only a narrow sandy strand at the shoreline. Massive efforts to divert the inland waters allowed the city to lay down imported sand to create the famous white sand beaches of Waikīkī that are maintained by periodic re-nourishment projects.

Diamond Head Crater, lying to the east of Waikīkī at the southern tip of the island, was formed during the Honolulu Volcanic Series rejuvenated eruptions. Diamond Head was built by hydromagmatic explosions that ripped through 200,000 year old coral reefs and Koʻolau basalt. As a result, large pieces of coral and basalt are mixed in the tuff and magmatic debris of the cone. The eruption most likely occurred in a very short period of time from days to perhaps a month, as suggested by the symmetry of the cone (Macdonald et al. 1986). The shoreline directly south of Diamond Head lies ~40 m below the road and is accessible only by footpath. The beach,



composed of calcareous sand mixed with terrigenous sediments, stretches for ~1 km and is one of the least developed vistas along the south shore. Black Pt., to the east of Diamond Head, is the last remaining remnant of a cinder cone located seaward of the modern shoreline, the majority of which has been lost to erosion.

East of Diamond Head and Black Pt. lies the broad Maunalua embayment fronted by one of the State's widest and shallowest offshore reef flats. The wide-ranging commercial and residential developments of the Kāhala, ʻĀina Haina, and Hawaiʻi Kai districts dominate the backshore in this area. Much of the Maunalua shoreline is armored with sea walls, revetments, and groins that protect valuable coastal real estate much of which is filled land along formerly sandy shoreline.

The east side of Maunalua Bay borders the Koko Rift coastline. The cinder cones of the Koko Rift are among the most obvious row of vents of the Honolulu Volcanic Series (Macdonald et al. 1986). The coastal extent of this group: Koko Head, Hanauma Bay, and Koko Crater is ~10 km and is essentially an undeveloped and natural shoreline.


Koko Crater
Reproduced by permission of USGS: Series I-2761

The back side of Koko Head makes up the east end of Maunalua Bay while the seaward edge, facing south and southeast, forms a rocky coast eroded by surface water runoff and wave erosion. The steep cliffs and strong currents

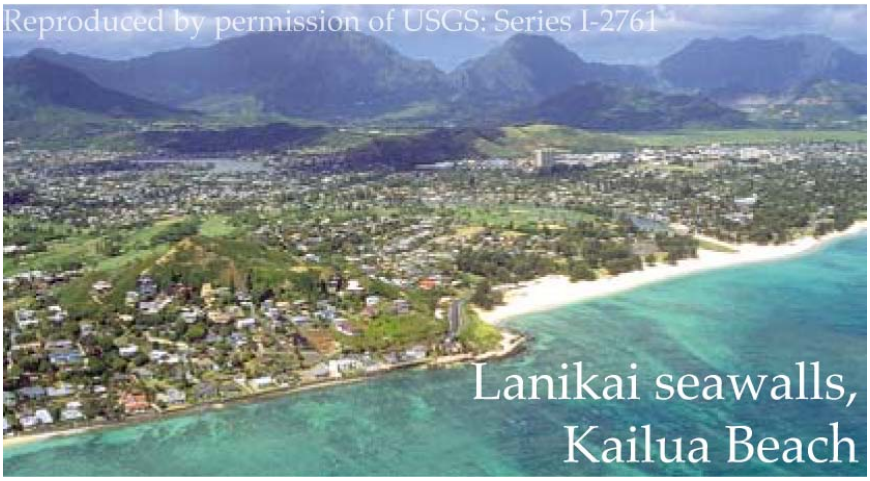
along this exposure help explain the lack of development here and the truly incredible vistas.

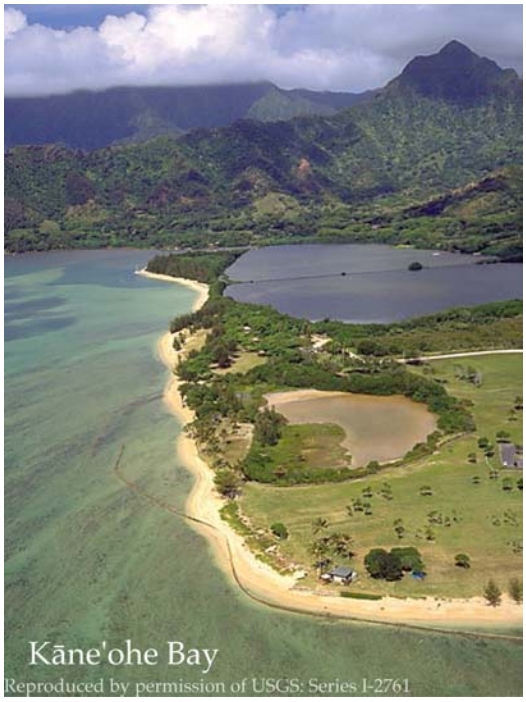
Hanauma Bay, central among the Koko Rift triplet, is the remnant of a cone that's low-lying seaward rim was eventually breached by waves, flooding the crater and creating a deeply indented bay. Hanauma Bay is backed by a wide calcareous beach and surrounded by the high near-vertical cinder walls of the cone. Wave erosion has cut a bench into the crater walls along both sides of the bay. Here olivine crystals eroding from the crater accumulate and mix with the calcareous sands, giving it a greenish hue. The Hanauma Bay Nature Preserve protects the live reef (1-6 m deep) that dominates the nearshore area and covers nearly 2/3 of the crater floor. The reef is home to thousands of aquatic animals that grow to full size in the protection of the preserve. The preserve operates under heavy visitor use with up to a million visitors each year coming to snorkel and dive amidst the abundant wildlife. It is the nation's most popular county park.

Beyond Hanauma, the southwest facing rocky coast is made up of the thinly layered flows from Koko Crater worn smooth by flowing surface water, and dipping toward the ocean. At the waters edge, the flows have eroded unevenly and protrude as a steep low cliff hanging irregularly over the ocean. This beautiful and rugged coast known as the Kaiwi coastline, trends northeast to Makapu'u Pt. and is interrupted by the calcareous sands of Sandy Beach Park. This beach park is home to a wide sand beach, moderate backshore dunes, and powerful shore break known throughout the State as an exciting big-wave body surfing site.

Between Makapu'u Pt. and the south side of Mōkapu Peninsula is a low

lying coastal terrace, made up of the broad sand bottomed embayments of Waimānalo and Kailua, bisected by the sandy Lanikai shoreline. The coastline is backed by vegetated dunes and well-developed residential neighborhoods. This northeast exposure is favored for swimming and offshore recreation because of the pristine natural state and the incredible water clarity. Large reaches of fringing reef lie in the shallow water offshore of Lanikai as well as limestone islates dating from the last interglacial and volcanic islets composed of intrusive dike swarms associated with the former Koʻolau shield. Lithified dunes at Waimānalo and Kailua Bay once held wave cut notches at 6.6 and 8.1 m above sea level (marking the last interglacial Waimānalo (+ 7.5 m) Stand of the Sea) but have since been removed to supply sand for construction (Macdonald et al. 1986).





Kāneʻohe Bay is tucked deep into the west side of Mōkapu Peninsula where it is protected by a wide barrier reef built

upon a large fossil dune, 3-5 km offshore. Kāneʻohe, the largest protected bay in the State, harbors a healthy estuary and the University of Hawaiʻi Marine Laboratory at Coconut Island (Moku o loʻe). Kāneʻohe sits at the edge of a low-lying coastal terrace abutting the steep eastern side of the Koʻolau Range. The shoreline within Kāneʻohe Bay is developed with seawalls, fishponds, and sea aircraft ramps and dredged channels. These constucted features are interspersed with isolated beaches of rocky mud, small mangrove forests, and shallow deltas of sediments deposited from the mountains nearby (Fletcher et al. 2002).

Low lying narrow beaches front the heavily armored shoreline north of Kāneʻohe Bay, where chronic erosion has resulted in significant loss of sandy beach. A broad fringing reef follows the coast to the north beyond Kahana Bay to Lāʻie at the northeastern end of Oʻahu.

The Lāʻie coast, consisting of sandy embayments, extends from Lāʻie to Kahuku at the north tip of the island. The Mālaekahana State Recreation Area and Lāʻie embayments are lined with unspoiled calcareous beaches backed by vegetated dunes on a low lying coastal terrace. South of Lāʻie Bay the shoreline is heavily developed and again, extensively armored. The sandy nature of the low coastal plain along the windward side, from Waimānalo to Kahuku, is the result of carbonate deposition under the +2 m seas of the Kapapa Stand ca. 3000 yrs BP.



Credits

Authors

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Charles H. Fletcher

Photos

Maps prepared by: Matt Barbee, Mary Engels, Eden Feirstein
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Source of base maps: 10 m USGS DEM's

Source of Photos: Fletcher, C.H., Grossman, E.E., Richmond, B.M., Gibbs, A.E. 2002 Atlas of natural hazards in the Hawaiian coastal zone. USGS Geologic Investigations Series I-2761. United States Printing Office.

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