CHAPTER 4

Moloka‘i—Two Different Types of Reef Growth in the Past 8,000 Years

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Reef growth in the main Hawaiian Islands during the current warm period (known as the “Holocene Epoch,” the past 10,000 years of Earth history) has been described in detail by only a few scientists, mostly conducting studies on the island of O‘ahu. These studies provide information that has been used to formulate a model of reef growth around the island of O‘ahu (Grossman and Fletcher, 2004, Fletcher and others, 2001). The model proposes three major components of the O‘ahu reef system, including (1) fossil reefs dating from the Pleistocene, a geologic epoch covering the period 1.8 million to 10,000 years ago, (2) reefs formed during the Holocene, and (3) a thin veneer of modern coral and coralline algae capping older reef structures or growing directly on volcanic rock.

According to the model developed for O‘ahu, Holocene reef growth was restricted to the narrow zone between the intersection of the sea floor with the wave base (the deep limit of water motion caused by waves) and the outer edge of the Pleistocene reef shelf ringing the island. Heavy wave action tends to limit reef development because of high shear stress on the sea floor, direct concussion, and sediment abrasion. At places around O‘ahu where reef growth has not been limited by waves (for instance, deeper portions of the reef in Kailua Bay and in protected Hanauma Bay), a sea-level rise of 1 to 2 m between about 4,000 and 2,000 years ago provided new environments for reef growth and sediment production (Fletcher and Jones, 1996; Grossman and Fletcher, 1998). Fletcher and others (2001) suggested that when sea level fell to its present position over the past few thousand years, reef development in shallow waters diminished and the centers of reef growth shifted from reef flat, reef crest, and upper fore reef to the lower fore reef and deeper waters seaward of the shallow island shelf. Their model assumes that the majority of Holocene growth on O‘ahu is limited to protected areas of low wave energy or to depths below wave base but still within the zone of sufficient sunlight to permit coral growth. One example of such a location is where ancestral stream channels cut through a fringing reef during periods of lower sea level.

The locations and histories of Holocene-age reefs around the other Hawaiian Islands are largely unknown, although the reports of Rooney and others (2004) and Engels and others (2004) shed light on reef growth on Moloka‘i and Kaua‘i. Rooney and others (2004) used cores of Holocene reef from Kaua‘i, O‘ahu, and Moloka‘i in support of a hypothesis that reef accretion during middle and late Holocene time was suppressed, and in places ended, by the onset of heavy North Pacific swell resulting from amplification of El Niño events about 5,000 years ago. Engels and others (2004) provided a model of reef accretion on the south shore of Moloka‘i that compared reef in the area of Hale O Lono wharf to reef at Wai a Kāne Gulch. That study is important for comparison to the O‘ahu system and thereby improves the overall understanding of how reefs developed in Hawai‘i during the Holocene.

Site Overview

The two reef sites chosen for this study are located at Hale O Lono wharf and Wai a Kāne Gulch, both on the southwest shore of Moloka‘i (fig. 1). These sites were selected for their close proximity but contrasting physical characteristics. At Hale O Lono, 5 km east of Lā‘au Point, sparse fields of live coral (mostly *Pocillopora meandrina*, *Porites lobata*, and species of the genus *Montipora*) grow on a much older (early Holocene) fossil limestone reef. The site does not have a typical reef structure (see Cochran, this vol., chap. 9). Rather, the sea floor is a fossil reef slope, interspersed with sand fields, that dips gradually away from shore. The amount of fine-grained terrestrial sediment in the water at Hale O Lono is typically small because of the arid nature of the adjacent uplands. But large amounts of runoff associated with episodic (seasonal) rainfall events may cause temporary turbidity lasting several days. Additionally, resuspension of carbonate sand can be significant during large swell events (see Bothner and others, this vol., chap. 19).

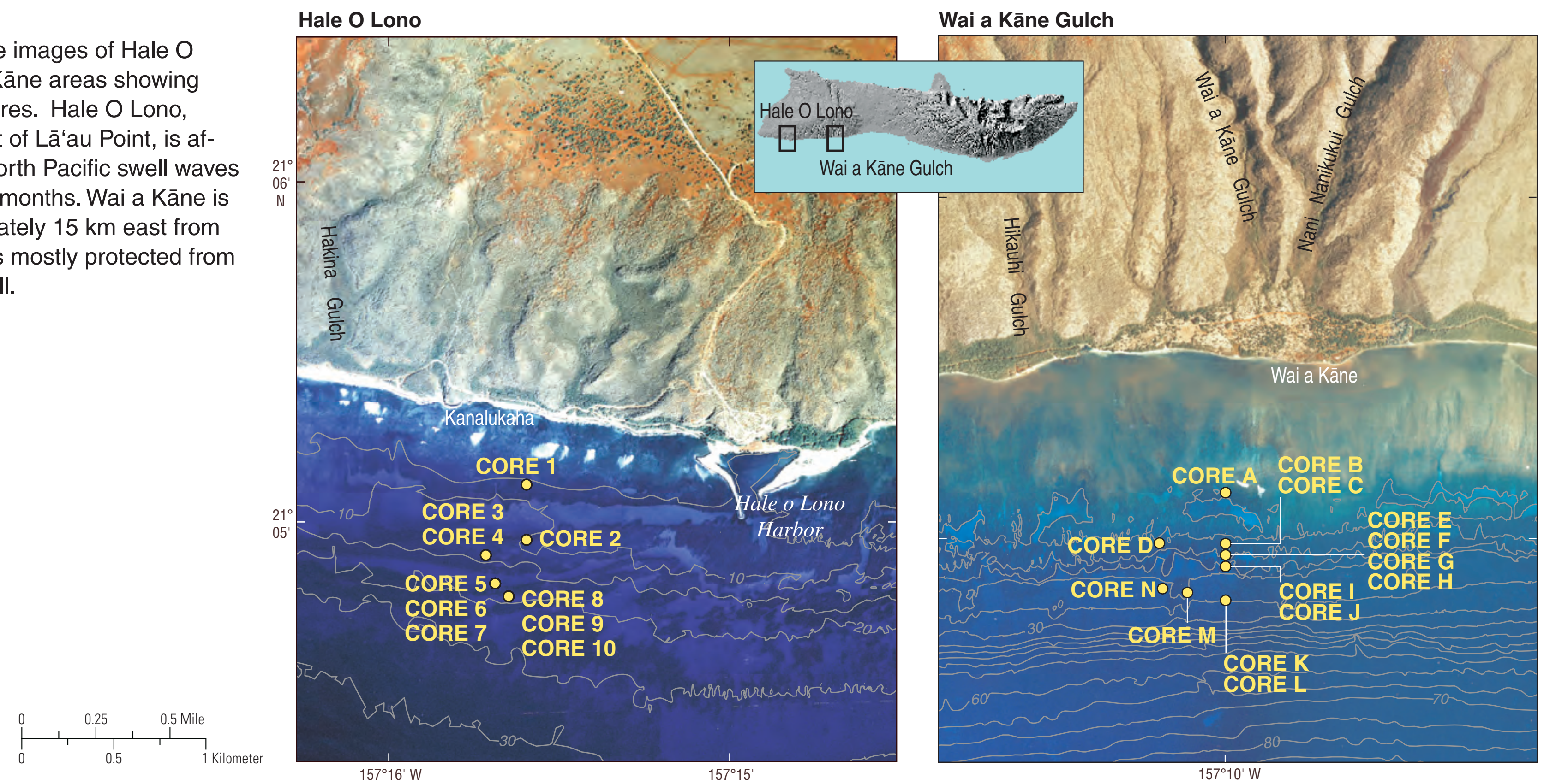

Figure 1. Satellite images of Hale O Lono and Wai a Kāne areas showing location of drill cores. Hale O Lono, located 5 km east of Lā‘au Point, is affected by large North Pacific swell waves during the winter months. Wai a Kāne is located approximately 15 km east from Lā‘au Point and is mostly protected from North Pacific swell.

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By contrast, Wai a Kāne, 10 km to the east of Hale O Lono, has a typical fringing reef structure with a reef flat, reef crest, and fore reef. The reef flat is buried under 2 cm to more than 1 m of fine terrestrial mud that comes from upland runoff (see Field and others, this vol., chap. 17). Live coral cover is low near the reef crest, perhaps suppressed by the high sediment content of runoff. Coral cover increases with depth across the fore reef, which is dominated by spur and groove features (see Field and others, this vol., chap. 2, and Storlazzi and others, this vol., chap. 3). The dominant sediment on the fore reef is carbonate sand.

Because of their close proximity (approximately 10 km), these sites experience a similar wave climate, with one notable exception—the reef at Wai a Kāne is protected from damaging North Pacific swell. During the summer, both sites are affected by Southern Ocean swell, Kona storm waves, and trade wind waves (see Storlazzi and others, this vol., chap. 11). During the winter months, trade wind waves diminish and North Pacific swell refracts around Lā'au Point, affecting Hale O Lono more than Wai a Kāne. The Hale O Lono site also commonly experiences strong tidal currents, being adjacent to the Kaiwi Channel that separates O'ahu and Moloka'i.

Methodology

For this study we surveyed the modern reef environment of western Moloka'i to develop an understanding of the community of corals and coralline algae under varying water depths and wave stresses. We use this understanding to interpret fossilized communities in drill-core samples at the two sites and reconstruct past wave stresses and water depths earlier in the Holocene. Details of the study are available in Engels and others (2004). The results of our survey are specific to the reef system on the western portion of the Moloka'i south shore. Our survey summary relates dominant members of the coral community, their growth forms and percentage cover, and percent coralline algae cover to water depth and wave stress (the force on the reef system due to wave action; see Storlazzi and others, this vol., chap. 11). By comparing fossil coral samples in drill cores to the present-day coral and algae distribution, we were able to determine coral communities, growth forms, and percentage coral cover of the fringing reef during past periods of the Holocene Epoch. These relations provide a method for inferring probable past water-depth and wave-stress environments that governed past reef development. From this we determined a likely geologic history for the reef at the two sites.

We surveyed the reef surface at each site using a technique called the line intercept technique. This technique consisted of placing a 10-m line on the reef surface and recording every change in the composition and character of the sea floor under the tape (fig. 2). Twenty-seven transects at Hale O Lono and 19 transects from Wai a Kāne were collected in a range of depths. More than 50 different kinds of information were collected, including depth, bottom type, coral types, algal types, growth morphologies, invertebrates, and others.

Figure 2. Information on the modern coral community structure is collected using a line intercept technique. In this technique a 10-m line is placed along the bottom, as shown in this image, and every change in bottom type is recorded along the length of the transect. The length of line viewed in this image is approximately 2.5 m.

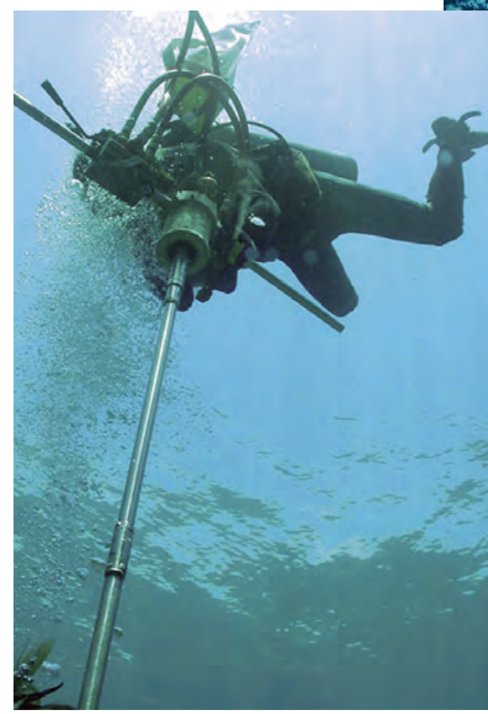

Figure 3. Divers working to reinsert the hydraulic drilling apparatus into a bore hole on the reef surface. For every section of core drilled, the full bit must be removed and then replaced with a new extension rod attached to an empty core barrel.

In order to collect reef cores, we employed a diver-operated hydraulic drill system (fig. 3). We collected 10 cores from Hale O Lono and 14 cores from Wai a Kāne. The cores averaged 2–5 m in length. All cores were split for archiving, then subsampled for ^{14}C radiometric dating (a method of determining age in years by measuring the concentration of the radioactive isotope carbon-14), X-ray diffraction analysis (a method of determining mineralogy and factors that might influence the measurement of sample age), and thin-section analysis (a rock preparation in which a sample is ground to ~0.03-mm thickness and mounted on a microscope slide to determine its structure and cementation history).

Results and Discussion

Results from the reef surface surveys were combined with modeled wave-induced near-bed shear stresses (see Storlazzi and others, this vol., chap. 11) to understand the relations to the modern, depth-related coral/algal assemblage (fig. 4). In general, coral cover increases with depth and with decreasing near-bed shear stress, while coralline algae cover increases with increasing near-bed shear stress. By comparing core samples (figs. 5, 6) to the modern coral/algal community, we were able to assess differences in reef accretion at Hale O Lono and Wai a Kāne.

The reef at Hale O Lono is early to middle Holocene in age, ranging from at least ~8,100 years old to ~4,800 years old, whereas the reef at Wai a Kāne is less than 1,000 years old. During early Holocene time, reef growth at Hale O Lono appears to have occurred in discrete events, with the centers of growth shifting landward under rising sea level. The rising sea level was responsible for opening new habitat for colonization, but it appears to have risen at variable rates throughout early to middle Holocene time. Indeed, there is a major change in the type of coral seen in some of the cores at Hale O Lono at an age between ~8,100 and ~7,900 years. One hypothesis explaining this change is that a rapid acceleration of sea-level rise led to sudden deepening of the sea floor, forcing the coral/algal community to shift from a shallow-water type to a deep-water type.

By about 4,800 years ago the reef stopped growing altogether at Hale O Lono, leaving the present fossil sea floor. Although there are live coral

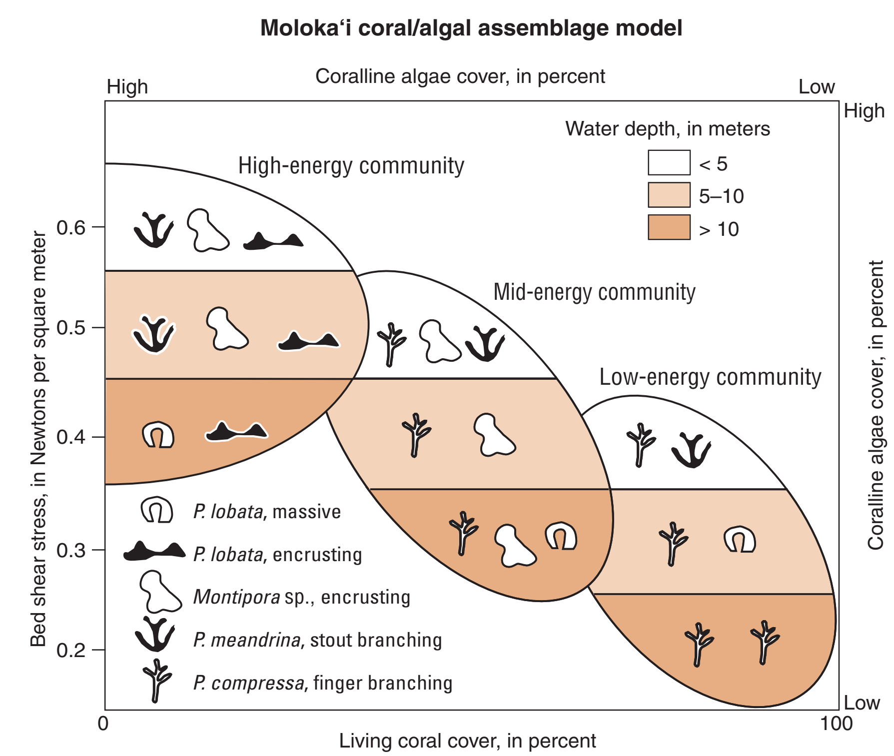

Figure 4. Model of the modern coral/algal assemblages on the south Moloka'i reef. This model (from Engels and others, 2004) relates wave-induced near-bed shear stress with percent living coral cover, dominant coral species, and coral morphologies. How these elements interact allow us to predict where different types of bottom cover (such as coral, coralline algae, sand, and rock) might be found on the reef.

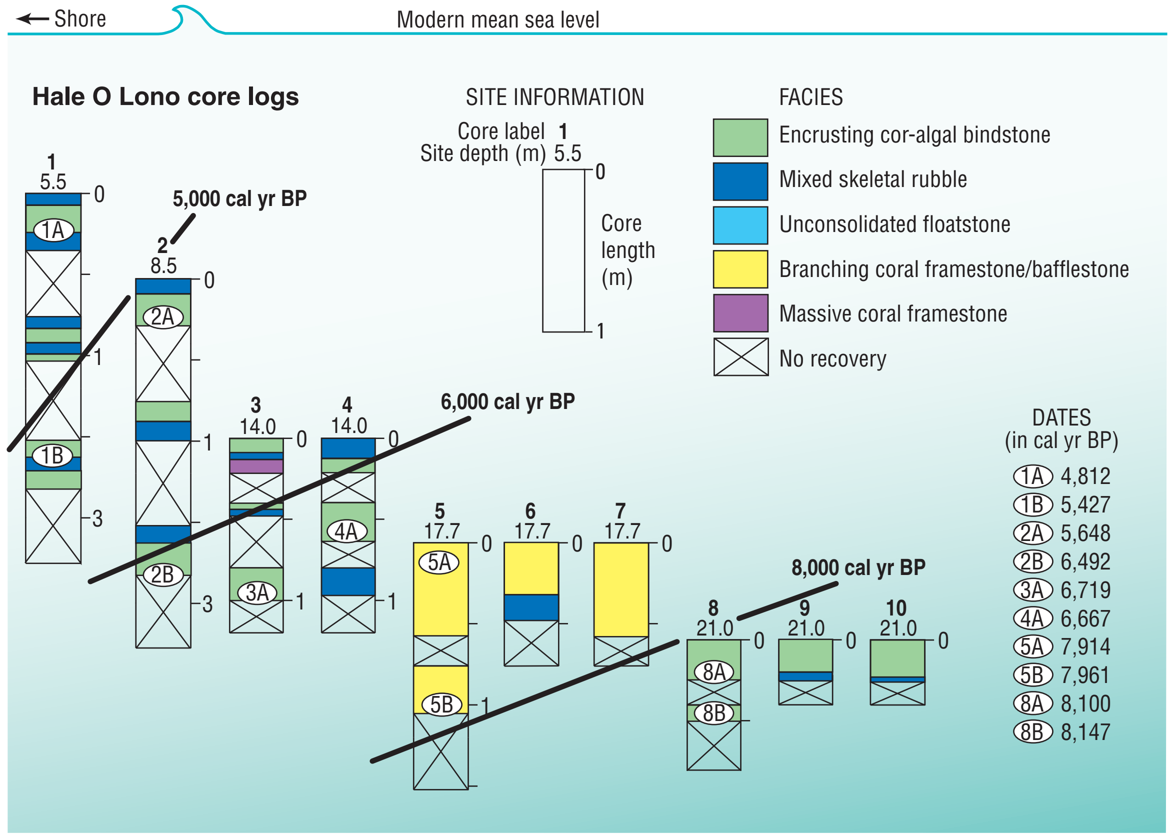

Figure 5. Drill core logs and radiometric dates from Hale O Lono. Limestones were classified according to the Embry and Klovan (1971) modification of the Dunham (1962) scheme. The age of the reef at the sea floor increases with distance offshore. No modern ages are associated with this site, suggesting little or no reef growth over the past ~4,800 yr. Contours indicate regions of similar age and highlight the shoreward stepping nature of reef growth in this area. The dominant rock type associated with cores 5–7 is branching coral framestone, a type of rock composed of a coral framework filled with carbonate sediments and then solidified. According to the modern coral/algal assemblage model, branching corals grow in low-energy, deep-water (>10 m) settings. Thus, their fossilized remains indicate a similar environment at the time of coral deposition ~7,900 yr ago. All the remaining cores at this site have coral types that are more closely associated with high-energy, shallow-water depositional environments. This distinct change in depositional environments suggests a possible rapid increase in the rate of sea-level rise ~7,900 yr ago, followed by a slowing of sea-level rise and a return to high-energy, shallow-water depositional environments.

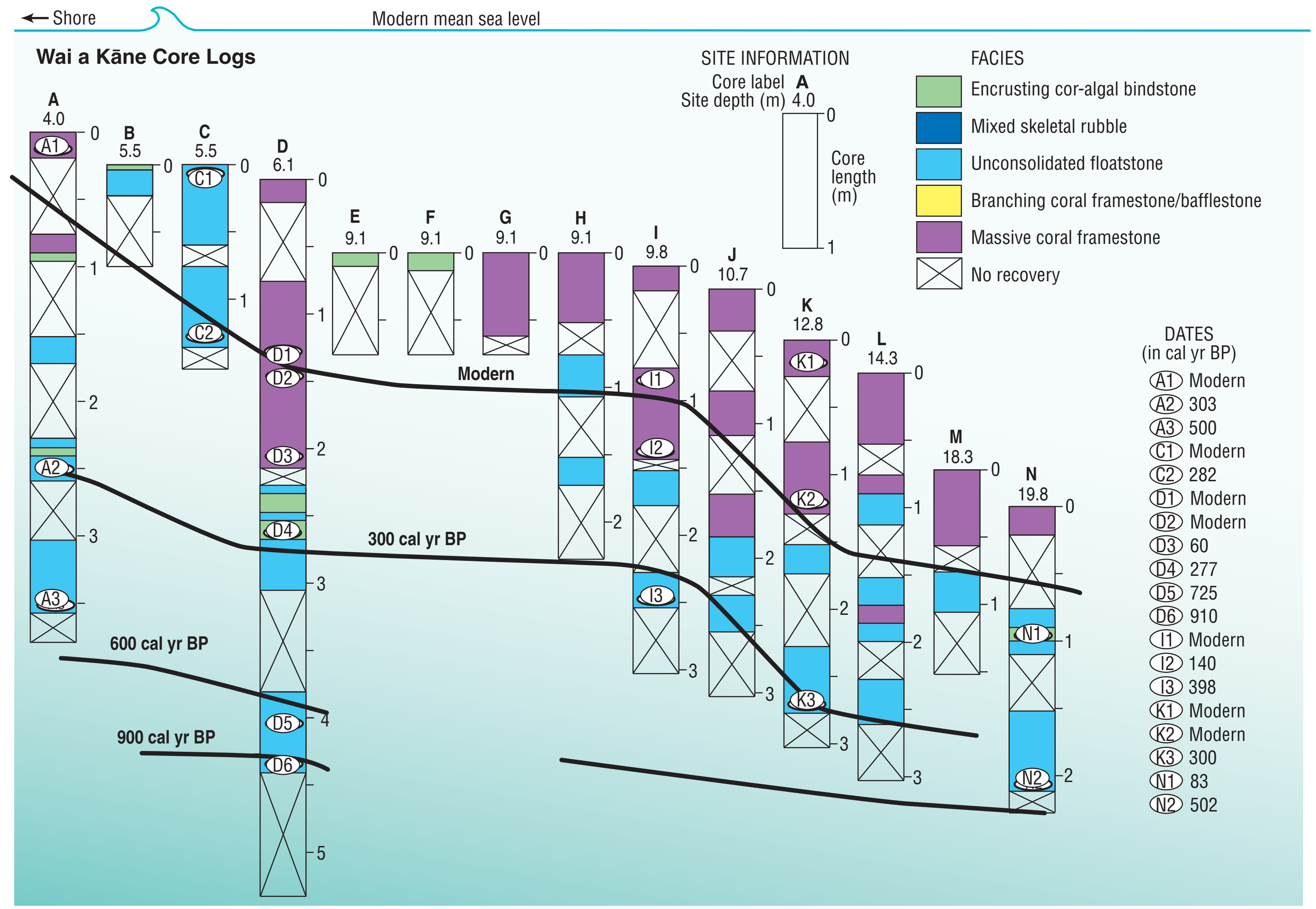

Figure 6. Drill core logs and radiometric ages from Wai a Kāne. Limestones were classified according to the Embry and Klovan (1971) modification of the Dunham (1962) scheme. This site is a young (< 1,000 yr) reef structure, extending seaward and upward from the deeper environment of the fore reef. Contours indicate regions of similar age and highlight the seaward stepping or prograding nature of this reef. The dominant rock type in these cores is unconsolidated floatstone (a type of rock in which chunks of coral rubble are surrounded by, or “float,” in a sediment matrix). The unconsolidated floatstones represent accumulated reef debris that has not yet had time to solidify into a reefal limestone.

colonies growing on this old surface today, the reef as a whole does not appear to be experiencing net accretion. The fact that there has been little net reef growth since ~4,800 years ago is likely a result of a combination of two things, (1) lack of new habitat, related to falling sea level following the “Kapapa” sea-level highstand in the late mid-Holocene (Grossman and Fletcher, 1998), further compounded by island uplift due to lithospheric flexure (Watts and ten Brink, 1989) and (2) an increase in El Niño Southern Oscillation (ENSO) intensity and accompanying increase in extreme levels of North Pacific winter swell, as suggested by Rodbell and others (1999), Moy and others (2002) and Rooney and others (2004). Corals may survive the typical north swell occurring during Hawaiian winter, but immense waves, often arriving during particularly intense El Niño years, may clear the sea floor of all accumulated growth since the last huge event and reset the sea-floor clock back to its 4,800-year age.

The young reef at Wai a Kāne, by contrast, has experienced significant accretion over the past 1,000 yr. The reef-flat area is limited by shallow water, sediment accumulation, and poor water quality related to the adjacent watershed. The reef crest is characterized by crusts of coralline algae and some encrusting coral growth. Seaward of the reef crest in less than 5-m water depth, reef development is limited by low accommodation space in the water column because of falling sea levels over the late Holocene and slow present rise of sea level. In deeper waters, greater than 5-m depth, thick stands of *Porites compressa* and other types of corals grow vertically. The reef is extending vertically and laterally (seaward) in this region because it is not limited by high wave energy and related shear stresses. Without rapidly rising sea level, the focus of reef growth has shifted to the deeper environments along the seaward margins of the reef, where there is room to grow outward and upward. At depths exceeding 15 to 20 m, reef growth is limited by substrate (sandy vs. hard bottom) suitable for colonization.

Age discrepancies between Hale O Lono and Wai a Kāne make direct comparison of growth histories impossible, but analysis of the sites together yields a picture of shrinking habitat suitable for reef accretion because of increased wave energy since the middle Holocene and lack of accommodation space because of falling or stable sea levels in the late Holocene. These combined conditions have caused the shift of net reef accretion from the area of the reef flat to the deeper waters of the lower fore-reef slope at Wai a Kāne, whereas at Hale O Lono high wave stress continues to suppress all reef growth. The Pleistocene foundation of older reef so prevalent on O‘ahu is not found on Moloka‘i, although additional drilling is necessary before this possibility can be confidently eliminated.

Consistent with the O‘ahu model, the major control on reef growth, at least on the western south shore of Moloka‘i, is wave-induced shear stresses from large interannual North Pacific winter swell, probably originating with amplification of the El Niño process in the middle Holocene. This factor would be accentuated and brought to greater influence by the falling sea level of the late Holocene and the relatively stable (slowly rising) sea level of the modern era. The setting of our studied reefs along a uniquely straight coastline provides the ability to examine the influence of high wave stress along a clearly definable gradient, where wave stress increases with proximity to Lā‘au Point. The fact that such different accretion histories were observed within a space of only 6 km proximity suggests how dynamic and amazing reef growth strategies can be within a relatively small area of generally similar environmental setting but differing wave influences.

Suggested citation:

Engels, Mary S., and Fletcher, Charles H., 2008, Moloka`i; Two different types of reef growth in the past 8,000 years, *Chapter 4 of* Field, M.E., Cochran, S.A., Logan, J.B., and Storlazzi C.D., eds., The coral reef of south Moloka`i, Hawai`i; portrait of a sediment-threatened fringing reef: U.S. Geological Survey Scientific Investigations Report 2007-5101, p. 37-40 [http://pubs.usgs.gov/sir/2007/5101/sir2007-5101_chapter04.pdf].