Florida Fish and Wildlife Conservation Commission
Fish and Wildlife Research Institute
100 8th Avenue S.E.
Saint Petersburg, Florida 33701-5020

OFR

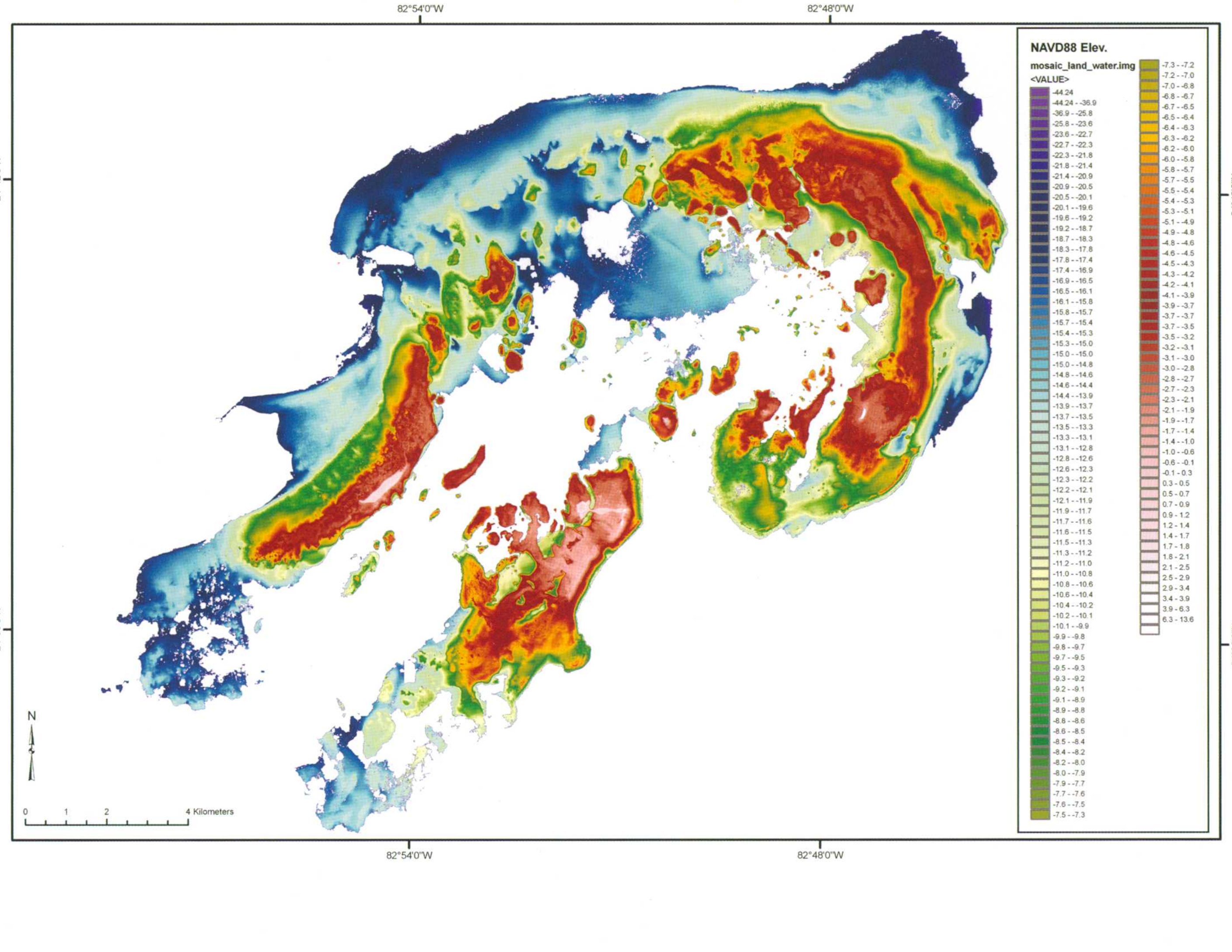
Erin Klein
8505 Research Way
Middleton, WI 53562

2005-1357

Field Guide to the Major Organisms and Processes Building Reefs and Islands of the Dry Tortugas: The Carnegie Dry Tortugas Laboratory Centennial Celebration (1905 – 2005)

Eugene A. Shinn, U.S. Geological Survey, and
Walter C. Jaap, Fish and Wildlife Commission, State of Florida

Dry Tortugas 2004 LIDAR Survey: Bathymetry



Field Trip and Symposium on the Past, Present, and Future of Research in the Tortugas
October 13-15, 2005, Key West, Florida

CENTENNIAL ORGANIZING COMMITTEE

Chairman
Robert N. Ginsburg
University of Miami
Rosenstiel School
rginsburg@rsmas.miami.edu

Dan Kimball
Superintendent
Everglades and
Dry Tortugas
National Park
dan_kimball@nps.gov

Billy Causey
Superintendent
Florida Keys
National Marine
Sanctuary, NOAA
billy.causey@noaa.gov

Gary Davis
Chief Scientist
National
Park Service
gary_davis@nps.gov

Walter Jaap
Florida Fish
and Wildlife
Conservation
Commission
walt.jaap@myfwc.com

Eugene Shinn
U.S. Geological
Survey
eshinn@usgs.gov

John Ogden
Florida Institute
of Oceanography
jogden@marine.usf.edu

Richard Dodge
National Coral
Reef Institute
Nova Southeastern
University
dodge@nova.edu

Carnegie Laboratory Centennial
Key West Florida October 13-15 2005

This celebration was made possible by the contributions of the institutions and individuals listed below.

Sponsors

- Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission
- Florida Keys National Marine Sanctuary
- National Park Service
- The Henry Foundation
- University of Miami Rosenstiel School of Marine and Atmospheric Science
- U.S. Geological Survey

Donors

- Carnegie Institution
- Charles Evans and Lisa Robbins
- Environmental Defense
- Harte Institute for Gulf of Mexico Studies
- Robert Ginsburg

Contributors

- Marshall Payn
- Nathaniel Reed
- National Coral Reef Institute
- The Nature Conservancy

tortugas@rsmas.miami.edu • fax 305-421-4931
University of Miami Rosenstiel School, ATTN: Karen Wilkening, Carnegie Laboratory Centennial
4600 Rickenbacker Causeway, Miami, FL 33149 USA

Field Guide to the Major Organisms and Processes Building Reefs and Islands of the Dry Tortugas: The Carnegie Dry Tortugas Laboratory Centennial Celebration (1905 – 2005)

Eugene A. Shinn[1], and
Walter C. Jaap[2]

[1]U.S. Geological Survey
600 4TH Street South
St. Petersburg, Florida 33701, USA

[2]Fish and Wildlife Research Institute
Florida Fish and Wildlife Conservation Commission
100 8TH Avenue SE
St. Petersburg, Florida 33701, USA

Alfred Goldsborough Mayor (1868-1922)

A son of the physicist Alfred Marshall Mayer and Katherine Duckett Goldsborough, Alfred Goldsborough Mayer (changed to Mayor in 1918) was born in Frederick, Maryland, on April 16, 1868. He earned a degree in engineering and began graduate work in physics, but in 1892, he decided to study zoology at Harvard University.

Soon thereafter, Alexander Agassiz, Director of Harvard's Museum of Comparative Zoology (MCZ), invited Mayor to coauthor a book on medusae and, later, to assist as a curator in the MCZ. Between 1892 and 1900, Mayor drew and described the medusae he collected around Australia, the South Pacific islands, the western Atlantic coast, and the Dry Tortugas. From 1900 to 1904, he served as the Curator of Natural History in the Brooklyn Museum.

In 1904, the Carnegie Institution of Washington approved Mayor's proposal to establish the Tortugas Laboratory on Loggerhead Key. Although he faced many problems there, Mayor succeeded admirably, attracting noted biologists to pursue important research and conducting studies of his own. In 1910, he published his monumental *Medusae of the World*. After completing an equally valuable work on ctenophores in 1912, Mayor began a series of pioneering studies of the ecology of coral reefs in the Tortugas region and in the South Pacific.

Married to Harriet Hyatt in 1900, he was the father of four children. Suffering from tuberculosis, Mayor died on Loggerhead Key on June 24, 1922. A memorial plaque, designed by his wife, was erected on the Laboratory site in 1923.

Dr. Lester D. Stephens

Contents

Field Guide to the Major Organisms and Processes Building Reefs and Islands of the Dry Tortugas: The Carnegie Dry Tortugas Laboratory Centennial Celebration (1905 – 2005)

Eugene A. Shinn, U.S. Geological Survey, and Walter C. Jaap, Fish and Wildlife Commission, State of Florida

This guide to the geology and biology of the Dry Tortugas is divided into four sections: 1) geologic and anthropogenic features you will pass on your trip to and from the Tortugas, 2) a summary of items of Tortugas geologic, historic, and human interest and what you will experience at Loggerhead Key while walking* and snorkeling, 3) a summary of recent coral-monitoring results, and 4) an Appendix with tributes to some of the significant research accomplishments of researchers at the laboratory between 1905 and 1939.

Section I

The approximately 2- and 1⁄2-hour trip to the Tortugas begins in Key West on two fast catamaran tour boats. Your course will be on the south side of the chain of islands that begin west of Key West (Fig. 1). The following areas of geologic, biologic, or historic interest will be pointed out and/or can be seen from a distance as we cruise along. Let's begin.

General composition of the limestone beneath your feet

If you drove to Key West, you passed along the emergent crest of the Key Largo Limestone, a Pleistocene coral reef that forms the upper and middle Florida Keys. The series of bridges you crossed in the lower Keys spans ancient tidal channels between bars of limestone, a pattern arranged

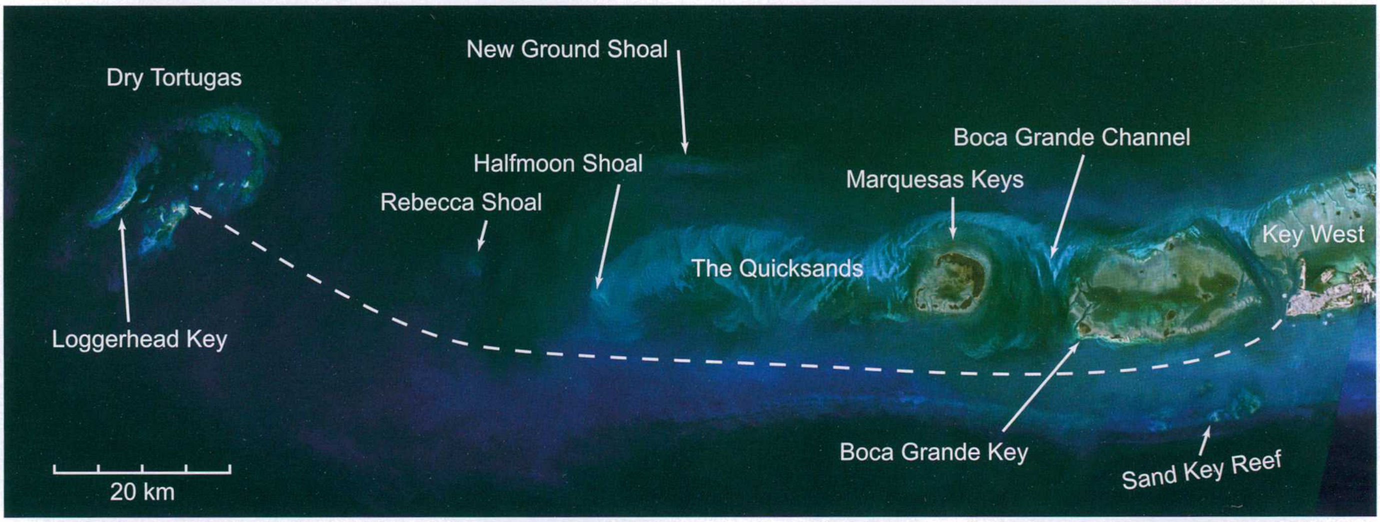


Figure 1. Enhanced Thematic Mapper Plus image, acquired in February 2000 from the Landsat 7 satellite, shows key geographic features and the fieldtrip route between Key West, Florida, and the Dry Tortugas.

*An interpretive ranger from the National Park Service will guide you at Fort Jefferson. Various books on the history of Fort Jefferson, culture, lighthouses, wildlife, and other aspects of the area are for sale in the bookstore inside the fort.

like the teeth of a comb. The reef-and-bar/channel complex developed about 125,000 years ago when sea level was some 7 m above its present position. Melting of polar glaciers caused the elevated sea level. Strong tidal currents moving back and forth across the lower Keys part of South Florida produced an unusual kind of round calcareous sand. Each of the near-spherical sand grains, known as ooids (**Fig. 2A**), is shaped like a pearl. It has a nucleus and is coated with concentric shells of calcium carbonate. Ooids precipitate in areas of strong reversing tidal currents. Once formed, currents shaped the ooids into tidal bars with intervening channels. Then sea level fell at least 120 m as the polar glaciers advanced, and the bars of calcareous sand were exposed to slightly acidic rain. The rain dissolved carbonate from the ooids, which again precipitated between the sand grains, gluing them together to form oolitic limestone or "oolite" (**Fig. 2B**). This oolite is called the Miami Limestone. The lower Keys are some of the last emergent oolite islands in the chain of keys. The same oolitic limestone extends below the sea surface for the first 64 km of our trip to the Dry Tortugas.

After crossing the Key West ship channel (another preserved Pleistocene channel), you will pass a shallow area of the platform that is actually a continuation of the lower Florida Keys oolite. The 1- to 3-m-deep platform, to your right, is dotted with about a dozen small mangrove islands. The last island on this part of the platform is Boca Grande Key (Fig. 1). After crossing another Pleistocene channel called Boca Grande Channel, you will pass by a large cluster of vegetated islands known as the Marquesas Keys.

The Marquesas Keys

Vaughan (1914a, 1914b), a principal scientist at the Carnegie Marine Laboratory, examined islands of the Marquesas and the Tortugas and called them both atolls. We know now that neither is an atoll in the classic Darwinian sense, like those in the Pacific, but Vaughan keenly determined the origin of both areas. He realized that the Marquesas Keys are composed of sediment rather than coral and that the primary sediment components are oat-flake-shaped segments of species of the common green calcareous alga *Halimeda*. Recent studies show these algal species grow rapidly. Hudson (1985) used alizerin-red stain to measure the growth rate of *H. opuntia* at the Marquesas and found that a single

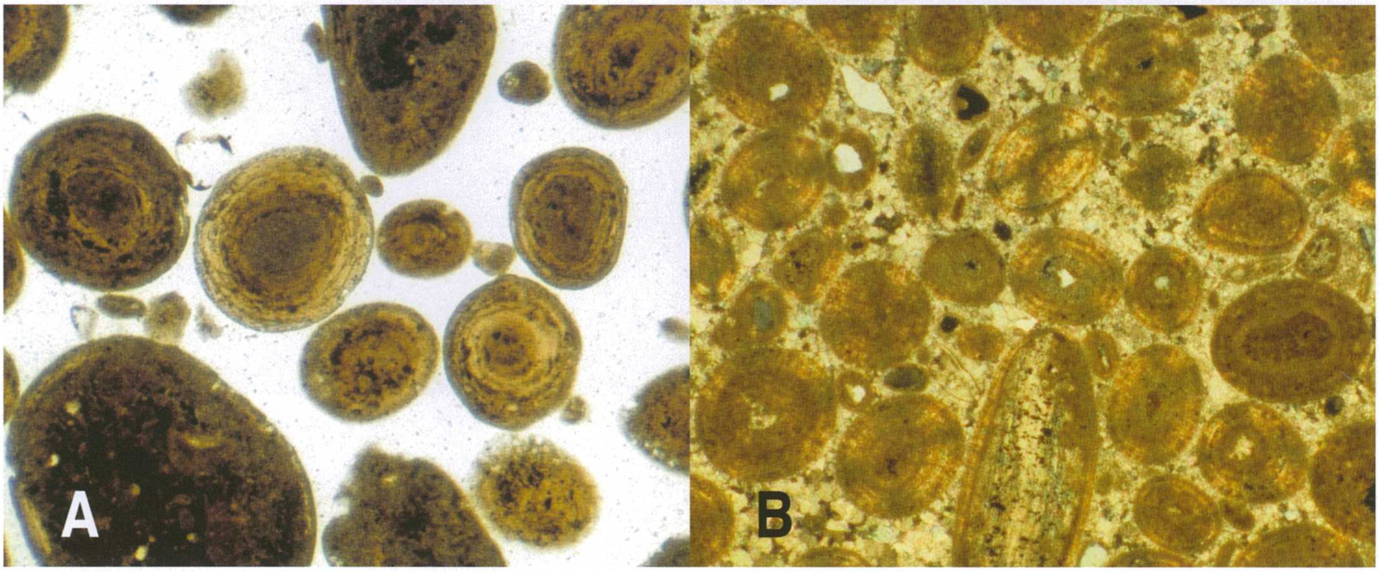


Figure 2. (A) Photomicrograph of modern ooids from the Bahamas (plane light). (B) Ooids cemented with calcite to produce the rock known as oolite. Much of the rock in the lower Keys and beneath the water and sediment between Key West and the Tortugas is oolite.

plate multiplied into 3,000 plates in just 125 days. *Halimeda opuntia* is the principal sediment producer, but there are several other *Halimeda* species here as well.

The *Halimeda* sands have been heaped by currents and waves to form an atoll-shaped cluster of vegetated islands (**Fig. 3**). The islands enclose a large lagoon (approximately 6 km across) where wave energy is sufficiently reduced to allow accumulation of fine-grained carbonate sediment. The lime-mud sediment is exposed at low tide, except within winding tidal channels that are scoured to bedrock. The sediment is heavily populated by marine grasses.

Extensive high-resolution seismic profiling, aerial photography, and rock coring were conducted in the Marquesas in the 1980s. These data, when contoured to create bedrock maps, show that the lagoon occupies a trough between two east/west-trending ridges of Pleistocene oolite (**Fig. 4**). Though Vaughan (1914a, 1914b) recognized the presence of oolite bedrock, he apparently was unaware of the two ridges. It is now believed that these two ridges focused development of the Marquesas Keys and

Figure 3. Aerial photograph shows the Marquesas Keys. The vegetated keys are mainly composed of uncemented *Halimeda* sand. The central area, often awash at low tide, is soft carbonate mud and silt, with admixtures of *Halimeda* sand. The sediment is in places >5 m thick. Many tidal channels lack sediment, exposing bedrock. Notice the hooked vegetated spits on the lagoon side of the northern islands, indicating westward migration of the islands.

lagoon. The northern ridge, just 1- to 1.5-m deep, clearly helps protect the northern side of the Marquesas islands from erosive waves when storms blow from the north.

The linear rock that forms the northern ridge was a Pleistocene beach and is composed of laminated northward-dipping oolite (Shinn et al., 1990; Lidz et al., 2005). In contrast, the ridge on the south side was not a beach. It is about 2 m below sea level and is composed of non-bedded, highly bioturbated oolite. The depth to bedrock beneath the fine-grained sediment in the lagoon between the two ridges is approximately 5 m (Fig. 3). The two parallel rock ridges merge into the relatively flat 30-km-long, 10-km-wide Marquesas-Quicksands ridge shown in Figure 4 (Shinn et al., 1989, 1990; Lidz et al., 2005).

Overall accretion of the Marquesas Keys is toward the west, under the influence of prevailing easterly winds. Accretionary spits indicating westward buildup are obvious in aerial photographs at the west end of the northern island. Newly formed sand spits at the Marquesas are quickly overtaken and stabilized by intertidal red-mangrove forests, a process observed by the authors in recent years. Erosion dominates the eastern margin of the islands.

Large patches, or cushions, of *Halimeda opuntia*, some 1 to 2 m in diameter, can be seen growing on and, in some instances, smothering the sea grass within the shallow lagoon. Shallow lagoonal sediments extend at least 0.5 km westward beyond the confines of the enclosing *Halimeda* sand islands.

The Quicksands

The area known as The Quicksands is an extension of the Marquesas Keys/lagoon complex and rests on, and is influenced by, the underlying Marquesas-Quicksands oolitic ridge (Shinn et al., 1989, 1990; Lidz et al., 2005; see **Fig. 5**). The Quicksands are characterized by submarine mega-ripples, sand

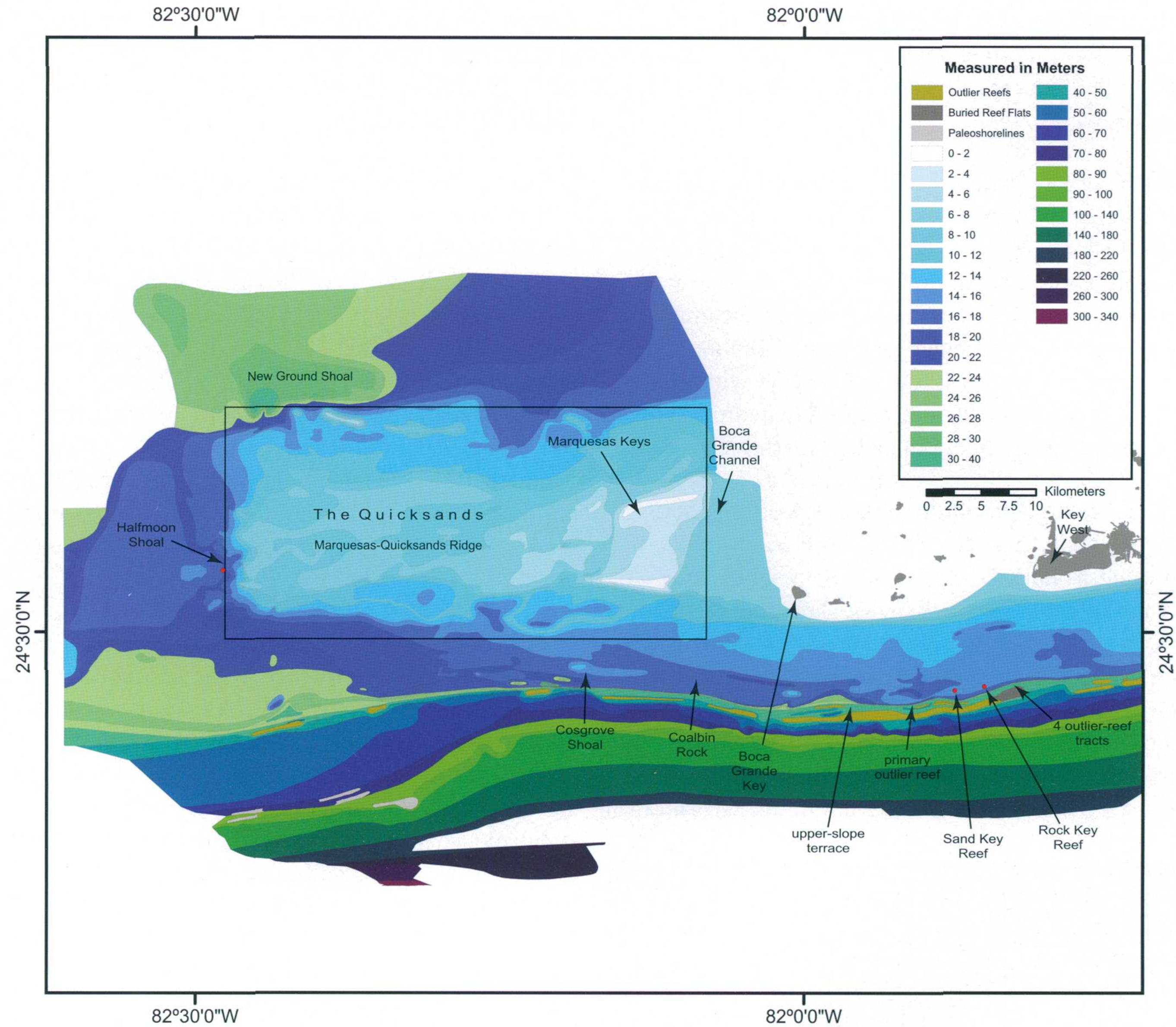


Figure. 4. Colored contour map shows the bedrock surface topography beneath Holocene reefs and sediments in the area of the Marquesas-Quicksands ridge and its adjacent surrounds. Areas of no data are white. Note the narrow shallow rock ridges on the north and south sides of the Marquesas Keys and the westward orientation of the main ridge. The main ridge is surrounded by deeper bedrock. The bedrock below New Ground Shoal is coralline limestone, whereas that on the shallower Marquesas-Quicksands ridge is oolite. (From Lidz et al., 2003, 2005).

dunes, and tidal bars. The dunes, which overlie the oolite, are as much as 2 m high and break the sea surface in sporadic areas at low tide. Like the Marquesas Keys, they are composed primarily of *Halimeda* sand. Arranged with their long axes oriented east/west in response to north/south reversing tidal currents, the dunes have been observed migrating several meters north or south with each tide. In some areas, the sand has coalesced to form north/south-trending tidal bars ornamented with the east/west-trending dunes. The sand is often "pushed" into deeper water at the north and south ends of the bars during storms to form what are called spillover lobes (**Fig. 6**). Tidal-channel areas between the bars are populated by sea grasses and are the factory areas for *Halimeda* sand production. Pleistocene

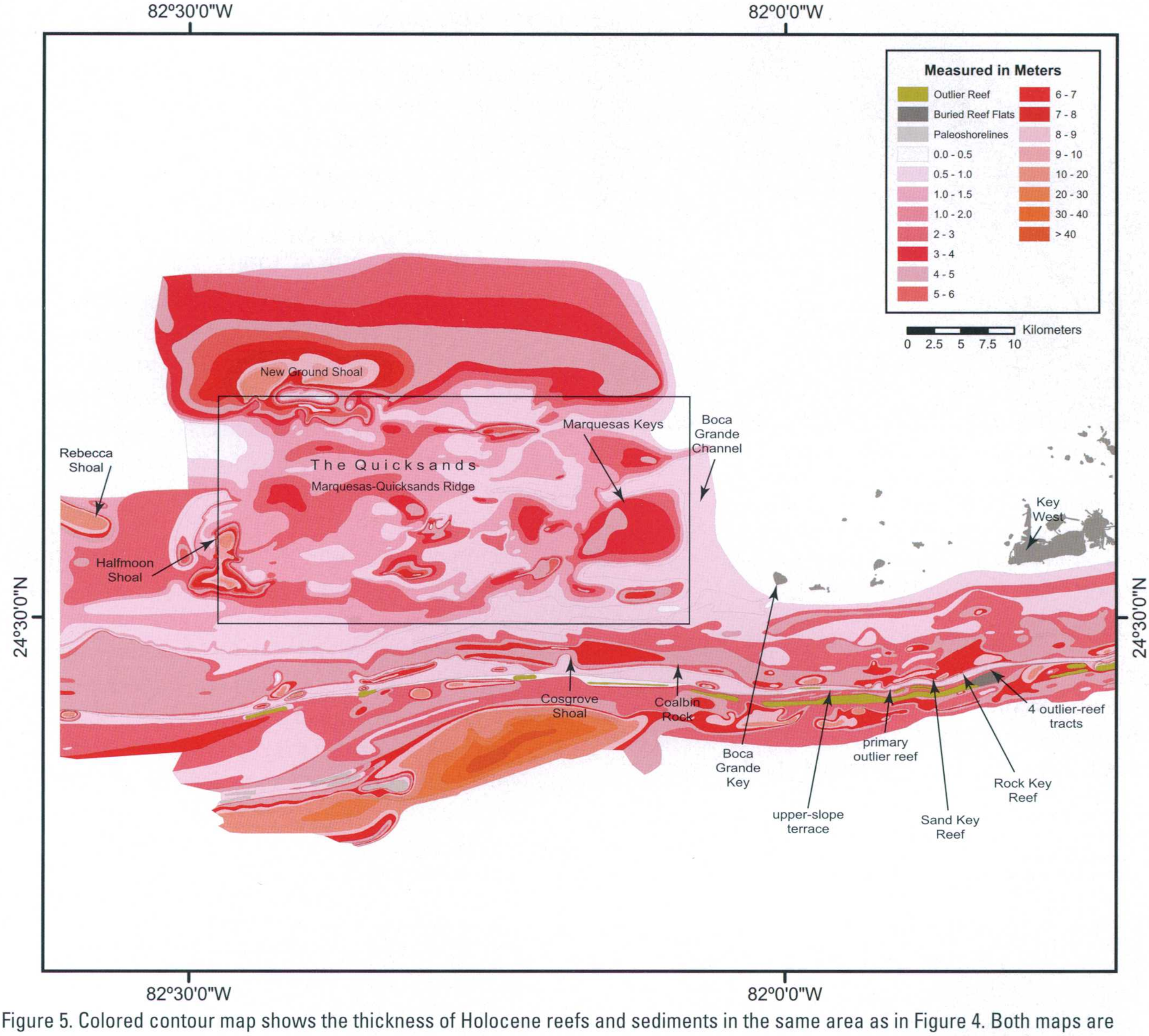


Figure 5. Colored contour map shows the thickness of Holocene reefs and sediments in the same area as in Figure 4. Both maps are based on data from high-resolution seismic profiles, standard marine charts, and aerial photographs. (From Lidz et al., 2003, 2005.)

bedrock is not exposed in the channels but has been observed where sediment was removed by treasure hunters (personal observation, EAS).

High-resolution seismic surveys show the sand is several meters thick and is more than 10 m thick at the western terminus of the Marquesas-Quicksand ridge where the accumulation is called Halfmoon Shoal. The contact between the Pleistocene ridge and overlying sand is readily visible in seismic profiles (Fig. 7). Vibra-coring shows the sand is cross-bedded, and internal dune bedding can sometimes be seen in seismic profiles. Tidal currents and the resulting bedforms appear identical to those observed in areas of the Great Bahama Bank where ooids are forming today (Hoffmeister et al., 1967). For unknown reasons, ooids are not forming in The Quicksands (Shinn et al., 1990). Wind direction, bedforms, and cross-bed dip directions indicate that the overall sand accumulation is migrating

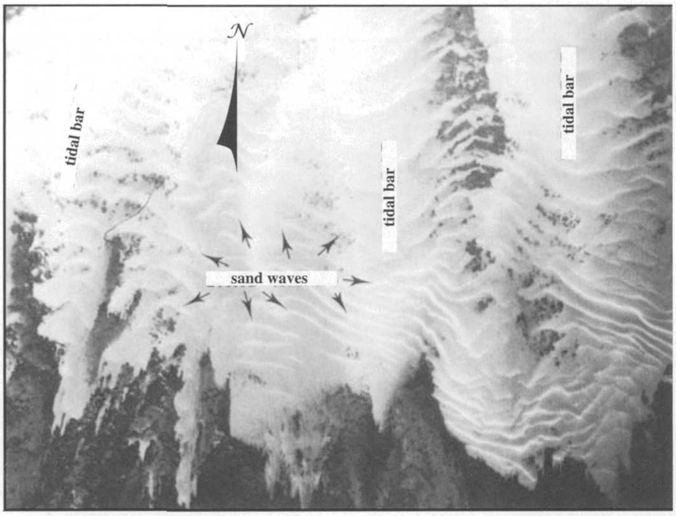


Figure 6. Aerial photomosaic shows a portion of The Quicksands west of the Marquesas Keys. Note the sand waves are perpendicular to the tidal bars. Color of dark areas between the sand bars is due to presence of marine grasses and *Halimeda*. Sands on the ridge are composed primarily of fragmented *Halimeda* plates. (From Shinn et al., 1990.)

westward and filling an unnamed channel east of Rebecca Shoal (Shinn et al., 1990). The channel is a >20-m-deep, tide-dominated gap separating the Marquesas-Quicksands ridge from the shallow platform beneath the Tortugas islands farther west.

Coral reefs south of the Marquesas Keys

The south route to the Tortugas takes you past the south side of the Marquesas and Quicksands and passes over an extension of the Florida reef track. The geology and habitats of the reef tract off the Florida Keys have been studied for many years and are summarized in the subsurface and benthic habitat maps of Lidz et al. (2005, 2006). The shelf lagoon trough known as Hawk Channel off the Florida Keys extends to the south and southwest, deepens off the lower Keys, and continues to deepen as the reef track arcs westward in the vicinity of the Marquesas Keys and Quicksands. The depth and generally murky water in this western area have hindered mapping studies.

The last major platform-margin reef along our route to the Tortugas is Sand Key Reef (Fig. 1). Sand Key Reef is marked by the prominent lighthouse that can be seen southwest of Key West and is best known for its four tracts of outlier reefs that developed on a 30- to 40-m-deep upper-slope terrace (Lidz et al., 1991, 2003). Smaller reefs that are no longer growing, termed senile reefs by Lidz et al. (2005),

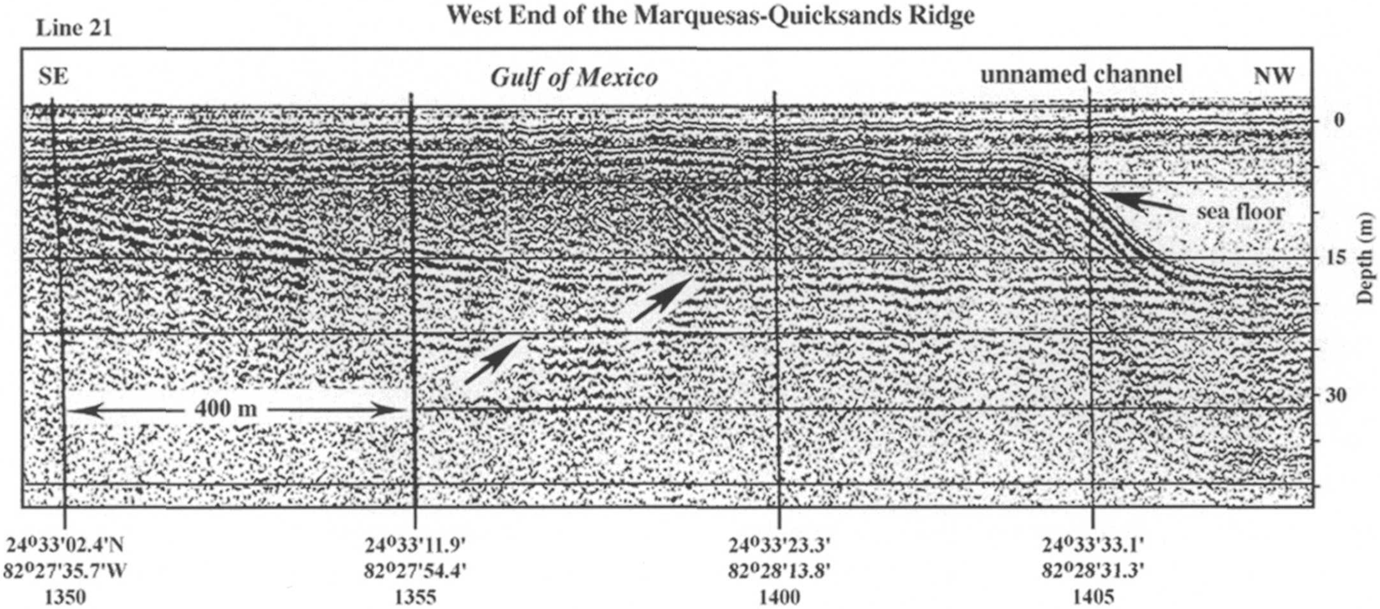


Figure 7. An east/west section of a high-resolution seismic profile near the west end of The Quicksands shows westward accretion of sediments. Cross laminations are apparent in the thick Holocene buildup, as is the contact between uncemented sand and underlying oolitic bedrock (top arrow).

continue westward along the platform margin to a point south of Halfmoon Shoal. The reef tract ends approximately at the beginning of the unnamed channel that separates the Marquesas-Quicksands ridge from the Tortugas part of the platform. There are two small shoals within the channel, Rebecca and Isaac Shoals, that are discussed later. Little is known of this deep area, and neither seismic nor benthic surveys have been conducted here. Patch reefs similar to those off the Florida Keys are scattered within this westward extension of Hawk Channel. For more information, see the Florida Keys benthic habitat maps recently prepared by Lidz et al. (2005, 2006).

North side of Marquesas-Quicksands ridge

Although points of interest along the north side of the Marquesas are under water, both geologists and biologists should be interested in some of the features found there. A few kilometers north of the Marquesas, a navigation marker marks a small dead Holocene reef called Ellis Rock. Ellis Rock is located on the east end of an east/west Pleistocene limestone ridge. Core drilling and seismic profiling have shown that corals at Ellis Rock once grew on a topographic feature thought to be an isolated Pleistocene coral patch. The corals are visibly similar to the Key Largo Limestone that forms the upper and middle Florida Keys. The Key Largo Limestone, originally called the Key Largo Formation (Sanford, 1909), was considered a facies of, and thus the same age as, the Miami Limestone (Hoffmeister et al., 1967; Halley and Evans, 1983).

Farther west is another marker on a much larger linear accumulation called New Ground Shoal. Core drilling and seismic profiling have shown that New Ground Shoal is a 7-m-thick dead Holocene reef situated atop an east/west ridge of Key Largo Limestone. The cores both here and at Ellis Rock show that Holocene *Acropora* species did not build these reefs (Shinn et al., 1989). There are several areas of sediment-free limestone between Ellis Rock and New Ground Shoal. [See seismic cross section in **Figure 8** from Shinn et al. (1990) and sediment thickness map in Fig. 5 from Lidz et al. (2005)]. North of the area between Ellis Rock and New Ground Shoal, the bottom deepens and grades transitionally from lime sand to an extensive area of lime mud and silt (Figs. 5 and 8). This large area is part of an area known as the Key West or Tortugas Shrimping Grounds. Seismic profiles and unpublished data from a sediment core taken in 23 m of water show that the sea floor consists of lime mud and silt with a restricted lagoonal mollusk fauna near the bedrock boundary. The muddy grass-free Holocene sediment here is 7.5 m thick. The restricted mollusk fauna at the base of this section is similar to that presently living in northern Florida Bay, described by Turney and Perkins (1972). The sediment and restricted fauna were most likely deposited when sea level was much lower and the platform underlying The Quicksands was still above sea level.

Rebecca/Isaac Shoals and dementia

About 10 km west of Halfmoon Shoal and within the unnamed channel are two shoals, Isaac and Rebecca. Neither shoal has been cored or investigated thoroughly, but they are thought to be dead Holocene coral reefs resting on preexisting Pleistocene coralline limestone, similar to the feature at New Ground Shoal. Rebecca Shoal is the shallowest, rising to about 3 m depth. It has long been a hazard to navigation.

In 1886, the Lighthouse Service installed a lighthouse on iron pilings at Rebecca Shoal. The lighthouse at times was home to a keeper, his family, and an assistant. One keeper went mad and jumped into the sea, and another keeper died of unknown causes. With no land in sight, events like this were not uncommon in the early days of manned lighthouses. Because of high and repeated maintenance

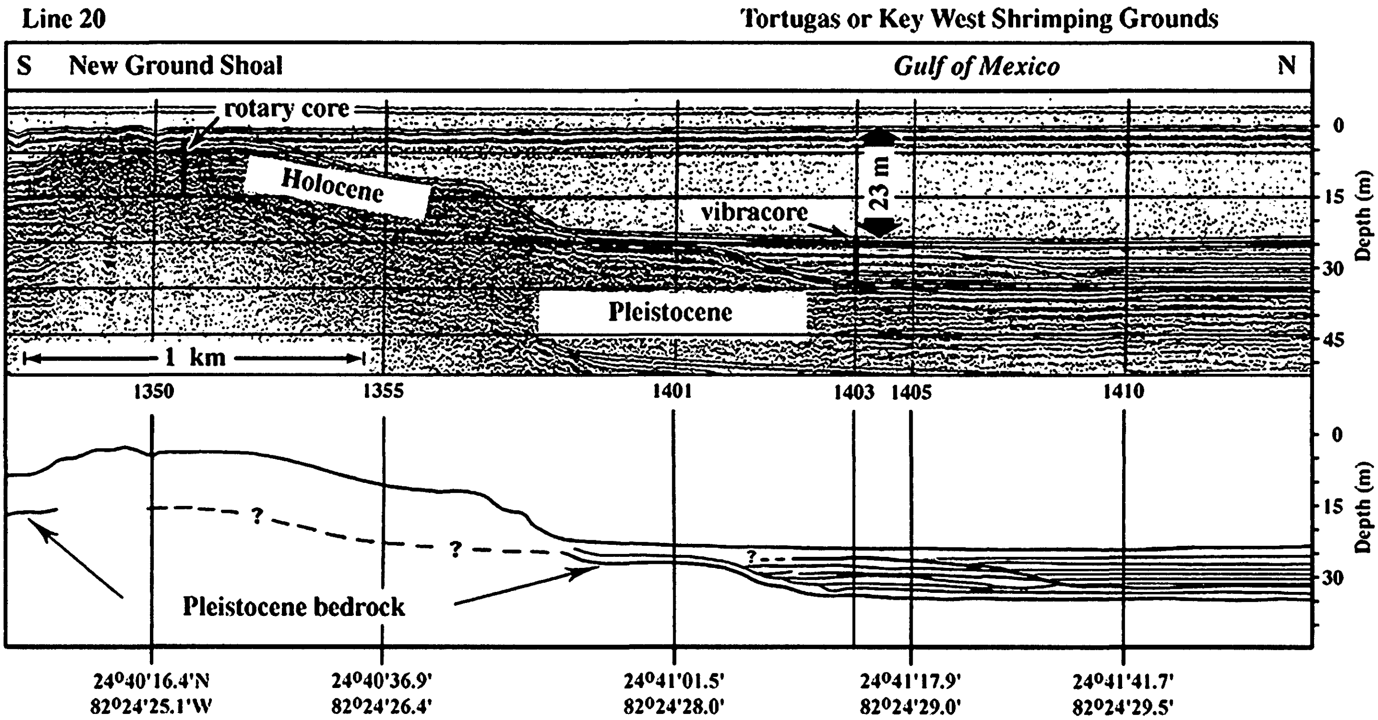


Figure 8. A north/south section of a seismic profile shows changes in the seafloor surface and composition from across the reef at New Ground Shoal into the muddy carbonate sediments of the Shrimping Grounds. The profile also shows location of a core through the Holocene coral accretion, confirming depth to underlying Pleistocene coralline limestone, and location of a sediment vibra-core in the Shrimping Grounds.

costs, the lighthouse was removed from the pilings in 1953 and replaced by a simpler structure with an automated light. In the early days, the light was serviced by the Lighthouse Service buoy tender and supply ship *Arbutus* and later by a newer ship built in 1904 called the *Ivy** (Dean, 1992).

Shipwrecks and their treasured cargos

Numerous ships, probably hundreds, have sunk and/or gone aground along and near the route to the Tortugas. The most notable shipwreck is that of the Spanish treasure galleon, *Nuestra Señora de Atocha*. In September of 1622, the *Atocha* slammed into a patch reef southwest of the Marquesas Keys, apparently in the swale of a huge rogue wave during a hurricane. Its bottom, along with 24 tons of silver ingots and numerous other treasures, was gutted and settled on the coral patch in about 15 m of water. The late treasure hunter Mel Fisher, his family, and dozens of assorted divers searched The Quicksands for 10 years finding artifacts, gold chains, and cannons. They also located the sister ship *Santa Margarita* near the southern edge of The Quicksands. Finally, on July 20, 1985, they found the main body of treasure on the patch reef by following the discontinuous trail of artifacts. It was clear that the upper part of the galleon had broken away from its bottom and drifted up on The Quicksands, dropping artifacts along the way. The treasure came with a price. Fisher tragically lost his son and daughter-in-law when their command and sleeping-quarters boat overturned in the middle of the night. Fisher had been searching for treasure in the Florida Keys for 16 years before he found his treasure.

*The first author's father was radio operator on the *Ivy* between 1932 and 1933.

The old Coast Guard buoy tender, *Arbutus*, with its engines removed was anchored on The Quicksands by Mel Fisher to help stake his claim. The mast of the sunken *Arbutus* still protrudes from the water on the north side of The Quicksands. Untold treasures were recovered from the *Atocha*, and many are exhibited in the Mel Fisher Museum in Key West. For more information on treasure and Florida Keys lore, see *The Florida Keys Environmental Story* by Gallagher et al. (1997).

For the past 60 years or more, the Navy has grounded derelict ships on The Quicksands where they have been used for target practice. Many have crumbled away, been bombed beyond recognition, or have been removed.

Halimeda and Hollywood

Farther west and mostly buried in the *Halimeda* sands of Halfmoon Shoal lies the wreck of the *Valbanera*. The large cargo and passenger ship grounded here during a hurricane in September 1919 (Barnette, 2003). The precise date of grounding is not known but is believed to be around September 12th. The ship was carrying more than 400 Spanish emigrants headed for Havana, but the hurricane on September 9 prevented safe entry into Havana Harbor. The captain apparently made way for Key West Harbor but grounded on Halfmoon Shoal. Most of the ship is buried beneath the shifting *Halimeda* sands, but the hull protruded above the water surface until the late 1930s. Passengers were said to have been locked in the hold below decks. There were no survivors. The sinking formed the basis of a 1940s Hollywood film, "Reap the Wild Wind," in which John Wayne (in a diving helmet) fights another diver and a giant octopus in the hold of the sunken ship.

Oil wells

The recent threat of oil drilling off the Gulf Coast of Florida has captured much public attention in South Florida and the United States in general. Few citizens are aware that 14 exploratory wells had been drilled in the Florida Keys decades ago. Five were drilled along the route to the Tortugas (**Fig. 9**). Four were drilled in the 1950s, and one was drilled as recently as 1962. Two >3,900-m-deep (12,850 ft) wells were drilled in Boca Grande Channel near the Marquesas Keys and three others were drilled on the reef tract southwest of the Marquesas (Fig. 9). Gulf Oil drilled the last well in 11 m of water from a 14-legged jack-up rig in 1962. Imprints from the jack-up legs are still visible in the reef southwest of the Marquesas. Impacts from all five sites have been examined, and the data, observations, and photographs of the sites have been published (Dustan et al., 1991). Impacts were mechanical and were determined to be minimal where iron "junk" and tools had not been discarded overboard. Oil was detected in lower Cretaceous limestone in all the test wells, but none were considered economically viable for commercial development.

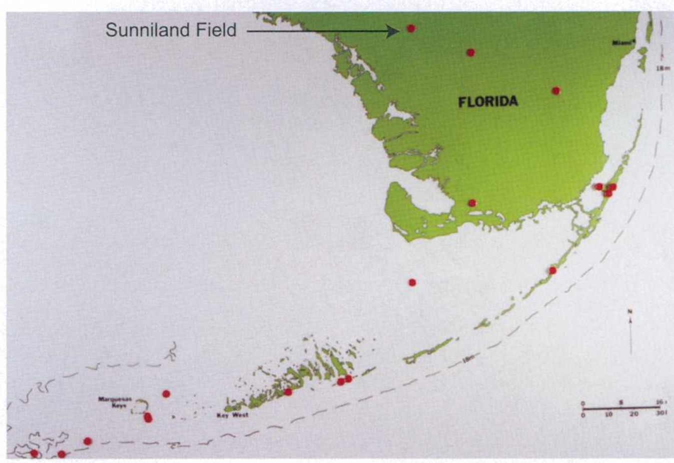


Figure 9. Map of South Florida and the keys shows approximate locations of 14 exploratory but non-producing oil wells drilled before 1962 (red dots). The first discovery well at Sunniland was drilled in 1941. The Sunniland Field is one of 14 producing oil fields in South Florida.

Section II

Dry Tortugas: Is it an atoll?

Vaughan (1914a, 1914b) believed islands and reefs of the Tortugas, like the Marquesas, were atolls and noted their similar shapes and orientation. He recognized, however, that the Tortugas was constructed primarily of coral, which may explain his interest in coral growth rates (Vaughan, 1915, 1916). Vaughan also determined that the deep depression in the center of the ring of islands and reefs was not caused by dissolution of limestone. Vaughan (1914a, 1914b) deduced the presence of a preexisting rim that controls the location of present reefs. His determinations were made without benefit of core drilling or seismic profiling, and even more amazingly, he concluded that the buildup of corals was on the order of 15 m thick!

As you approach the Tortugas (**Figs. 10 and 11**), the first object you will likely see is Fort Jefferson (Fig. 11) on Garden Key. Before you reach the red brick fort, you will pass an isolated carbonate sand island called East Key. East Key, which often shifts in storms, serves as a nesting area for sea turtles. The largest and westernmost island in the distance

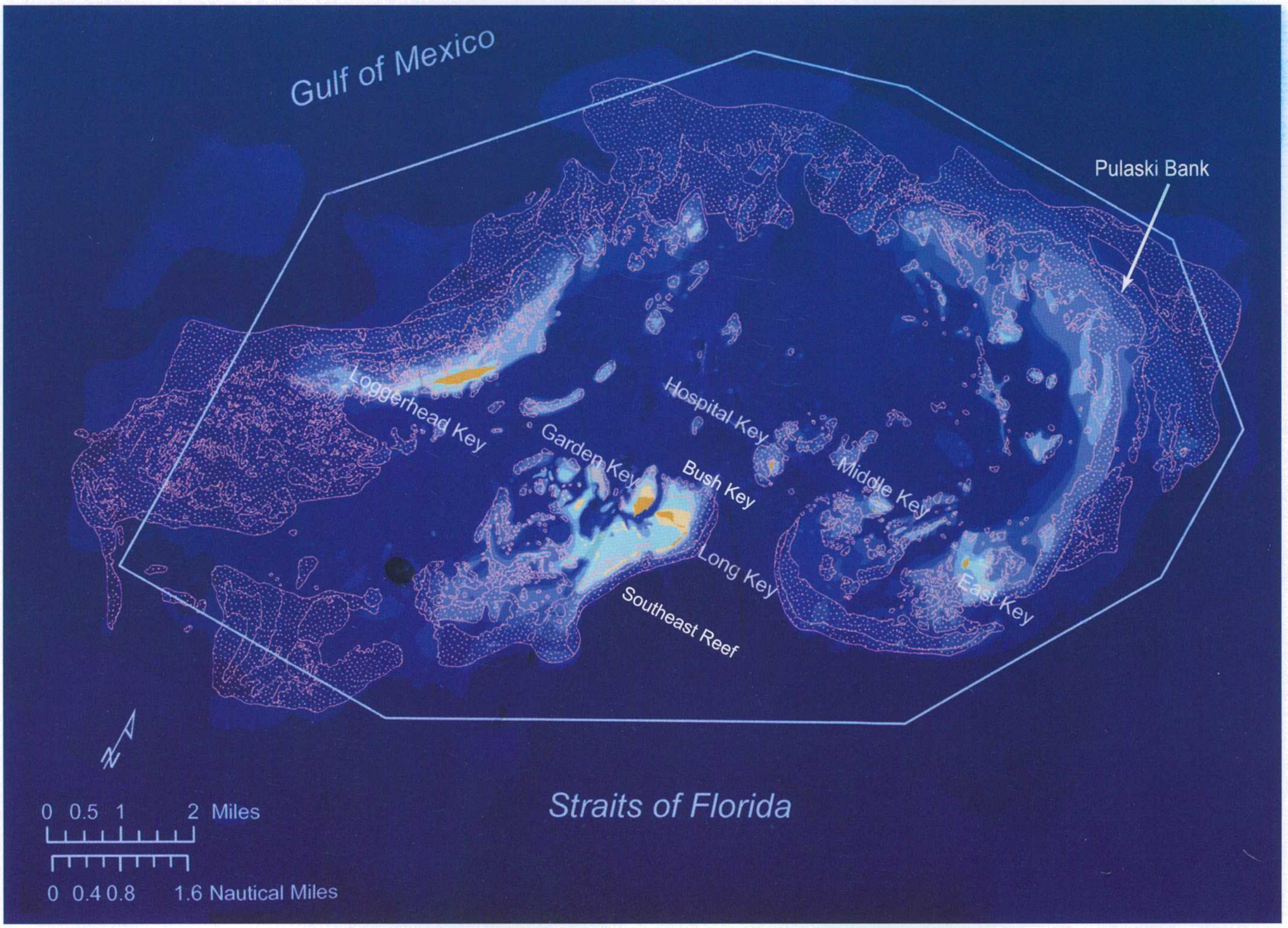


Figure 10. A map of Dry Tortugas National Park shows islands, major reefs, and the park boundary line. Compare this map with the LIDAR image on the guidebook cover. Also note the channel between Fort Jefferson (on Garden Key) and Bush Key to the east. Loggerhead Key, and site of the Carnegie Research Laboratory between 1905 and 1939, is the narrow north/south-trending island west of Garden Key.

Figure 11. A 2004 oblique aerial photograph of Fort Jefferson (on Garden Key) shows a sand land bridge with Bush Key in the background. Hurricane Katrina washed out the connection and opened the channel in August 2005. Scientists at the Carnegie Laboratory on Loggerhead Key often used the shallow waters of the moat around the fort to collect specimens and conduct experiments. The moat was used for sewage disposal when soldiers occupied the fort in the 1800s.

is Loggerhead Key. Loggerhead Key, our primary destination, is where construction of the Carnegie Laboratory began in 1904.

Discovery and early history

Dry Tortugas was originally named “Las Tortugas” by Spanish explorer Ponce de Leon because of the abundance of sea turtles. Ponce de Leon anchored off one of the Tortugas islands in June 1513 and recorded the killing of hundreds of turtles, birds (mainly pelicans), and many Caribbean Monk seals (Davis, 1982). Before refrigeration, these were the only sources of fresh meat.

In 1773, during the time England controlled Florida, George Gauld surveyed and mapped the Tortugas. Gauld named 11 sand and coral islands (Davis, 1982). More than 100 years later, in 1881, the benthic habitats were mapped by Alexander Agassiz (Agassiz, 1883). The mapping was driven by a desire to invalidate Darwin’s volcano-subsidence theory of atoll formation (Dobbs, 2005). Alexander Agassiz also examined many of Florida’s coral reefs for the Lighthouse Service in an attempt to devise a way to protect shipping. He concluded that lighthouses were the logical solution, because he could not determine how to keep the reefs from growing! Coral reefs were taking a heavy toll on shipping and in those days were considered a costly nuisance.

By Executive Order in 1908, President Theodore Roosevelt designated the Dry Tortugas as a wildlife refuge. The principal purpose was to protect bird rookeries. Dry Tortugas National Monument was established in 1935 when bird rookeries and cultural resources were still the chief concerns. In 1980, the enacting language was amended to include coral reefs and resident marine life. In 1992, without changing the boundaries, the area was designated Dry Tortugas National Park. The State of Florida, however, retained the rights of the seabed and associated resources. The park occupies approximately 259 km^2 (25,900 hectares), and the boundaries are marked by a series of yellow buoys placed beyond the reef margins in approximately 22 m of water.

Mapping and biological change

Using modern scuba, Gary Davis mapped the Tortugas benthic communities to determine natural

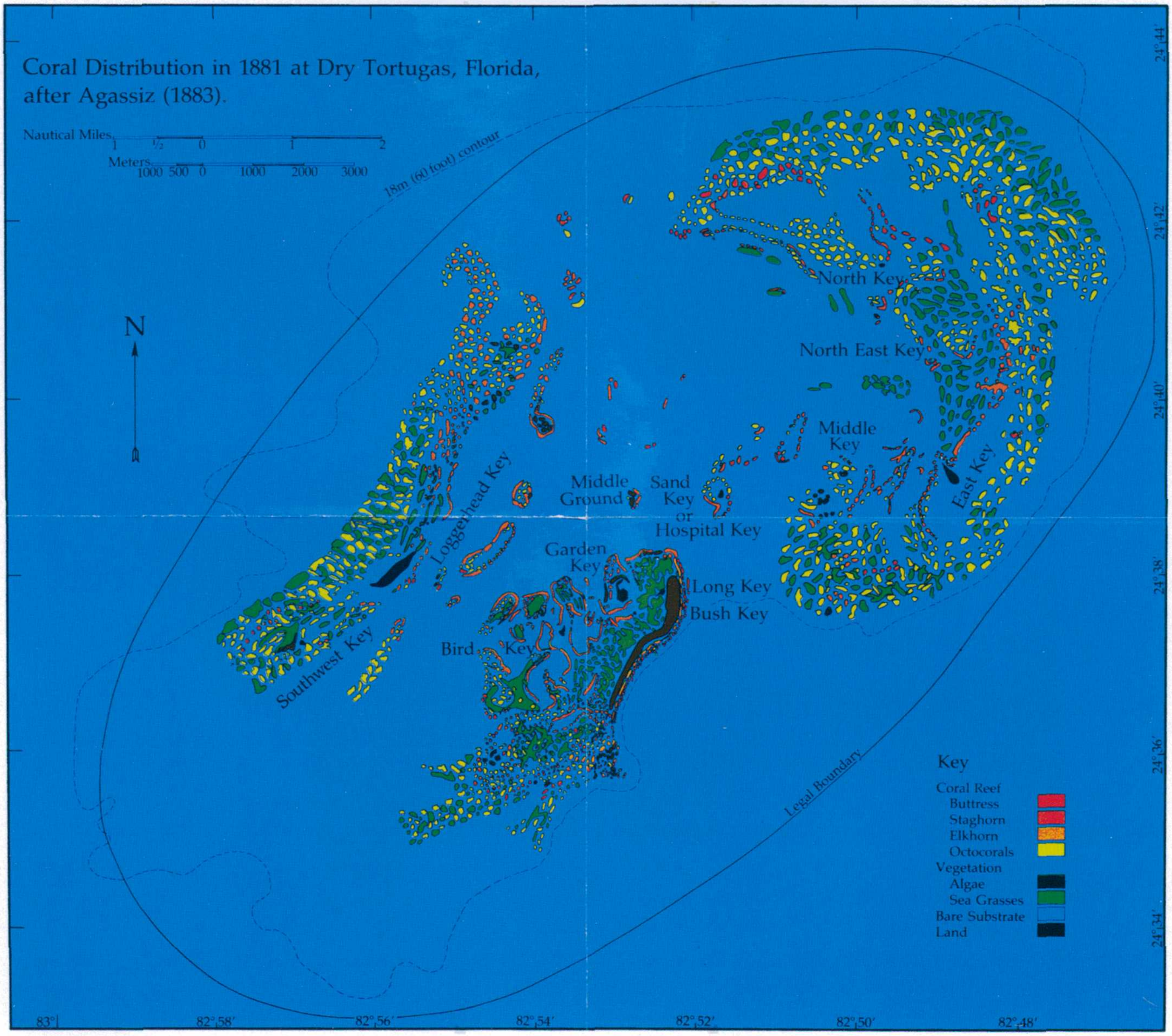


Figure 12. Reproduction of Agassiz's 1881 Tortugas benthic habitat map. (From Davis, 1982).

changes that had occurred since the time of Alexander Agassiz's map, completed almost 100 years earlier (Davis, 1979, 1982). Agassiz did his mapping just two years after the well documented so-called black-water event of 1879 that killed essentially all of the acroporid corals and many fish at Dry Tortugas (Mayor, 1903). The black-water event was probably a red tide and was associated with a major fish kill that virtually wiped out fisheries along most of the west coast of Florida (see reports in U.S. National Museum Proceedings, 1882). Not much was known about the cause of red tide in the 1800s. The 1881 Agassiz and 1976 Davis maps are reproduced in **Figures 12 and 13**. Although the percent benthic cover had changed little, species composition had changed significantly. Large areas formerly occupied by gorgonians had been replaced by the staghorn coral *Acropora cervicornis*. Ironically, in the year following the Davis map, more than 95 percent of the staghorn coral was killed by a severe cold front (Davis, 1982; Porter et al., 1982). The cold front of 1977 brought snow as far south as Miami and Homestead. The staghorn coral again recovered, but most began dying in the early 1980s, this time from thermal stress and/or disease. The demise of corals at the Tortugas and in the Florida Keys paralleled the general mortality of corals and sea urchins throughout the Caribbean.

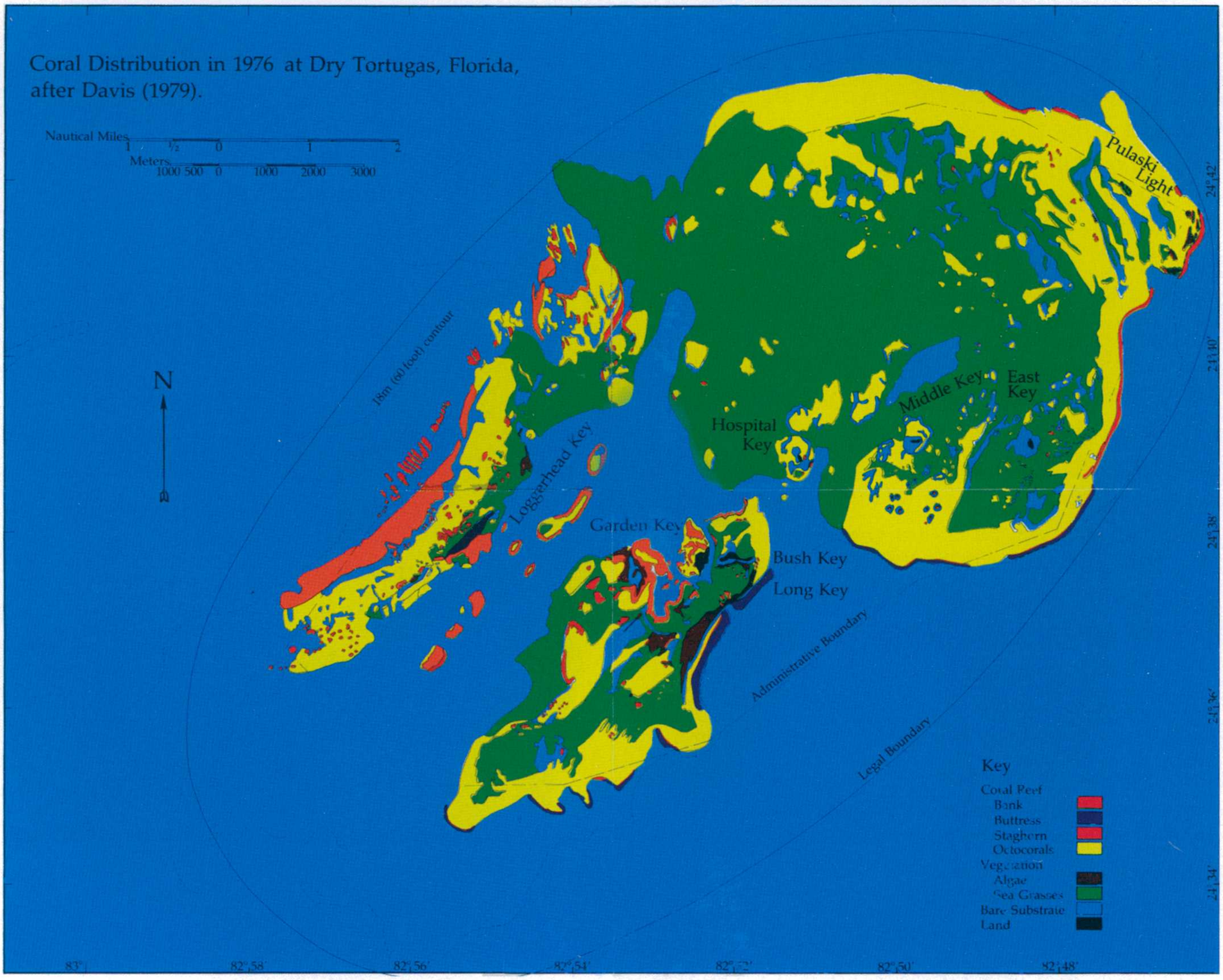


Figure 13. Reproduction of Davis' 1976 Tortugas benthic habitat map. (From Davis, 1982).

The algae-eating urchin *Diadema* died here in 1983, as it did throughout the Caribbean (Lessios et al., 1984). There has been little significant recovery of *Diadema* or corals here since the 1980s.

Only scattered patches of the staghorn coral *A. cervicornis* can be found living today, but there is a small dwindling patch of a closely related species, or hybrid, *A. prolifera*, on a patch in Five Foot Channel through Southeast Reef (Figs. 10, **14A**). *Acropora prolifera* is thought by some, including Mayor, who was cited by Vaughan (1910), to be a separate species. *Acropora cervicornis* also lives on the patch at Five Foot Channel. Interestingly, Vaughan (1910) commented on the black-water event of 1879 (reported by Mayer, 1903) that killed nearly all the *A. cervicornis* including many on the northwest side of Loggerhead Key. Vaughan further reported in his 1910 paper that, "now, however, they are rapidly reestablishing themselves, and have become fairly common on the flats west of Garden Key off Fort Jefferson, and on the flat north of Bird Key, in water 4 or 5 feet deep." (Note, Bird Key was washed away by a hurricane in 1935).

The elkhorn coral, *A. palmata*, as pointed out by Davis (1982), apparently was never a significant reef builder at Tortugas. Cores drilled by the USGS through 17 m of Holocene coral at Southeast Reef confirmed that *A. palmata* was not a significant builder throughout the 5,000 years of reef growth (**Fig. 14B**; Shinn et al., 1977). When the cores were drilled in 1976, only two small living colonies of *A. palmata* were noted on Southeast Reef. *Acropora cervicornis*, however, was abundant at that time (Davis 1982). *Acropora palmata* fragments are fairly abundant in the rubble that forms the emergent ridge at Southeast Reef. The second author and his colleagues have been, and still are, monitoring a patch where elkhorn coral is more abundant (discussed later in Section III). Nevertheless, none of the cores taken through reefs at the Tortugas indicate *A. palmata* was ever a significant Holocene reef builder as it was in the Florida Keys. The cores show that brain and star corals were the most abundant Holocene reef formers in the Tortugas. They were also the major builders of the Pleistocene reefs that underpin the modern reefs at Dry Tortugas (Shinn et al., 1977).

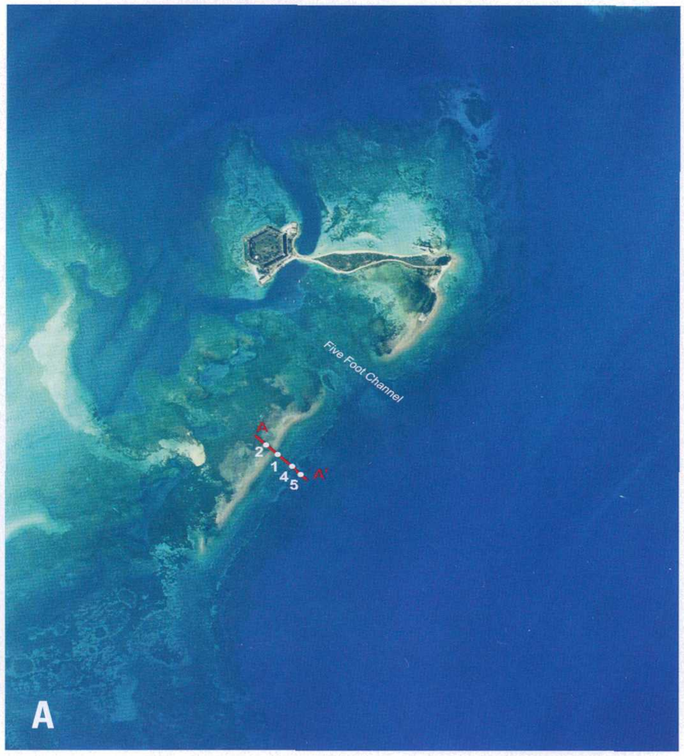
LIDAR

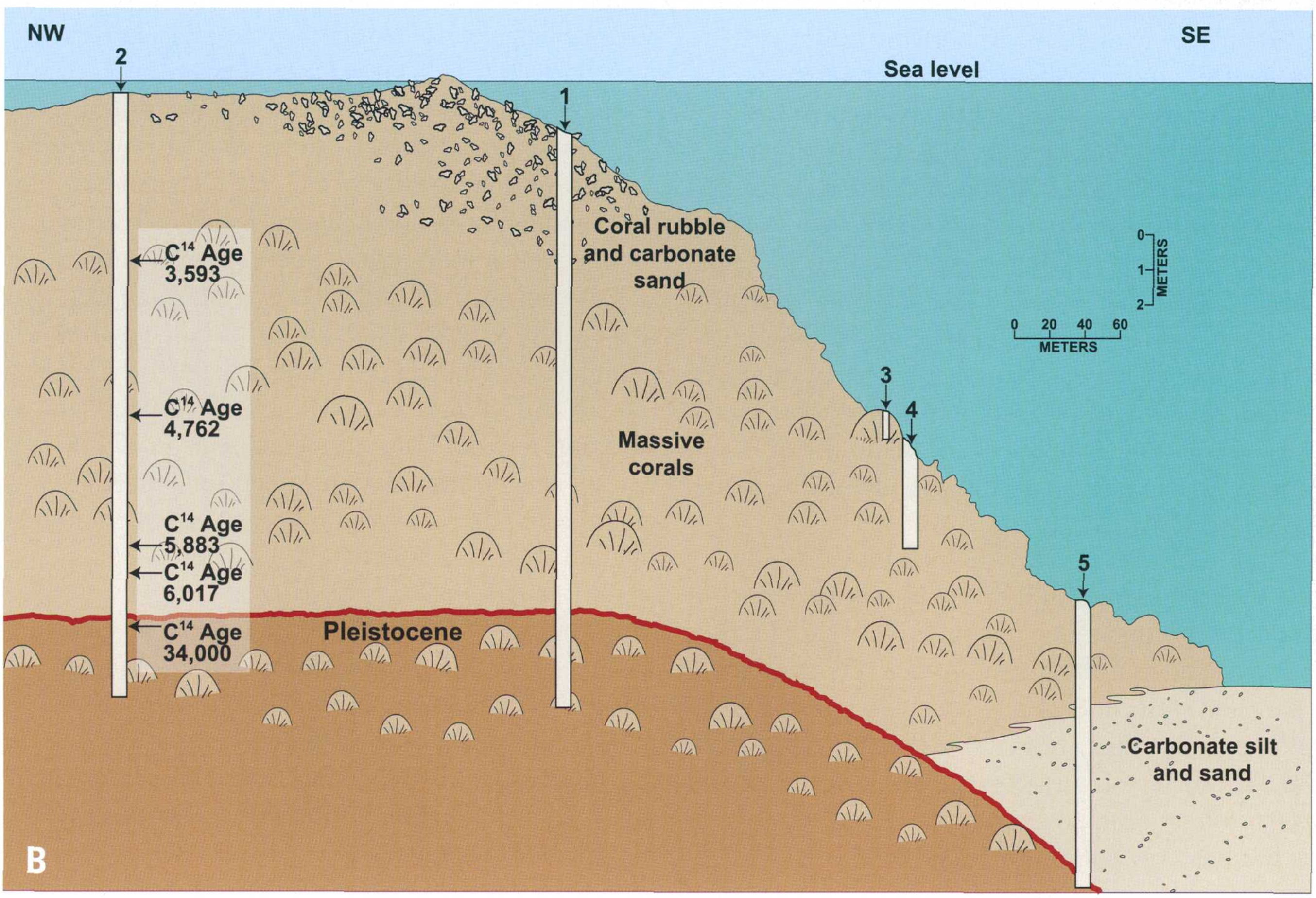
A new and continuing form of mapping at the Tortugas employs the use of LIDAR (LIght Detection And Ranging). The surveys, beginning in 2004, are a collaborative effort between NASA, the NPS, and the USGS. LIDAR surveys are conducted from an airplane using GPS and precise control, relative to a local base station. LIDAR surveying involves directing a pulsed laser beam through the clear water and measuring the timing of the reflected signal. It is essentially like a fathometer, or seismic profiler, that uses visible light instead of sound to measure the precise distance between water surface and the bottom. Maps created this way are far more accurate than existing topographic maps, many of which were based on centuries-old lead-line soundings controlled by triangulation, dead reckoning, and celestial navigation sextants. These new maps provide quick, accurate base maps for both geologic and habitat surveys. The cover of this guide shows a preliminary LIDAR map of the Tortugas.

Geologic underpinnings

As noted by Vaughan (1914a, 1914b) and Davis (1982), the Dry Tortugas is an elliptical atoll-like structure 17 km along its major northeast/southwest axis and 12 km on its minor axis (Fig. 10 and cover illustration). It is composed of three major banks, Pulaski in the northeast, Loggerhead to the west, and Long Key Reef (also called Southeast Reef) in the south. The banks are separated from each other by 10- to 20-m-deep channels.

Figure 14. (A) Aerial photograph of core transect (Shinn et al., 1977) across Southeast Reef, also called Long Key Reef and formerly known as Bird Key Reef prior to 1935. The transect area is the central part of the TRACTS 1 and South Florida/Caribbean Network, Inventory and Monitoring Program (SFCN-I&M) monitoring studies. Before 1935, Bird Key and an Audubon warden's house were located on the sandy area southwest of Fort Jefferson. Long Key is the vegetated island semi-attached to Bush Key. Bush Key had joined to Garden Key when image was taken. Note the deeper channel (Five Foot Channel) between the core transect and Long Key. (B) Geologic cross section of core holes drilled along TRACTS 1 transect (Shinn et al., 1977) showing configuration of underlying Pleistocene coralline limestone and ^{14}C-age dates of massive corals in core 2. *Acropora* species were not encountered in the cores.





The banks surround a 12- to 23-m-deep lime-mud-lined lagoon. Core drilling by the USGS in 1976 (Fig. 14A, B; Shinn et al., 1977) confirmed that the limestone beneath the lagoon is deeper than that beneath the outer-bank reefs. Vaughan (1914b) had reached this conclusion without the aid of drilling. Seismic profiles of Mallinson et al. (2003) also support this conclusion. Core drilling of Southeast Reef revealed the presence of a Pleistocene ridge beneath the Holocene reef (Shinn et al., 1977). These studies convincingly showed that the underlying Pleistocene coral reef topography serves as a template for overlying Holocene reef development.

Thus far, all mapping efforts have produced data that agree with Vaughan's (1914b) atoll interpretation, but the Tortugas are clearly different from classic Darwinian atolls in the Pacific. There are no subsiding volcanoes here. A good question to ask is, what constitutes an atoll?

In 1964, Gray Multer used a portable trailer-mounted rig to drill to a depth of 32 m in the parade ground of Fort Jefferson on Garden Key. He encountered Pleistocene coralline limestone at approximately 16.5 m. The coral-dominated limestone under the fort is overlain by Holocene carbonate sand and coral (Multer et al., 2002). In 2004, the USGS core-drilled in the parade ground to a depth of 19.5 m and recovered Pleistocene coralline limestone at approximately 16 m. Little else is known of the underpinning of the Tortugas except for a single 17-m-deep boring (unpublished) at the site of the Carnegie Laboratory dock that was drilled by the USGS in 1976.

In 1999, a team of USGS divers also drilled cores at the deeper Tortugas Bank about 7 km west of Dry Tortugas National Park in approximately 21 m of water. The Holocene there is about 10 m thick and is composed entirely of massive corals (Mallinson et al., 2003). The Pleistocene coral fauna there is similar to that of the overlying Holocene. Tortugas Bank is now under protection of the NOAA National Marine Sanctuary Program and fishing is prohibited in the area.

In summary, the most recent borings drilled in 2004 around and within the fort confirm that the fort was constructed on a little more than 15 m of Holocene sand and coral, thus explaining the settlement cracks in the bricks and mortar that appeared soon after construction had begun. A planned third tier was not added to the fort because of this unanticipated settlement.

Disappearing islands

There were 11 sand keys at the Tortugas when Agassiz mapped the area in 1881 and seven when Davis mapped it 95 years later. According to Davis (1982), one island, Bird Key, had disappeared during a hurricane, and others had merged to form single islands. As an example of shifting sands, the channel separating Garden Key from Bush Key was bridged (Fig. 11) on December 25, 2000. Until then, the channel had progressively been filling with sand moved from Bush Key by various storms and prevailing easterly winds. The channel became too shallow for boat passage after 1997. The land bridge shown in Figure 11 (photograph taken in 2004) was opened somewhat by Hurricane Dennis on July 9, 2005. Hurricane Katrina, however, widened the channel to its present state on August 26, 2005, just three days before it devastated New Orleans, and the Mississippi and Alabama Gulf Coast. Loggerhead Key sustained little damage; it is protected on both sides by beachrock. Beachrock will be discussed later.

The names of various islands and reefs have been changed over the years, causing some confusion for boaters and map makers. Bird Key, southwest of Garden Key, was washed away by the Labor Day hurricane of 1935. The Labor Day storm killed over 400 people in the Florida Keys and destroyed the Flagler Overseas Railway to Key West (Parks, 1968). The rail line was never rebuilt. The reef east of where Bird Key once existed was called Bird Key Reef until 1935. It is presently called either Long Reef (because it is an extension of Long Key) or Southeast Reef (because it is the southeasternmost reef at the Tortugas. The shallow Five Foot Channel runs through the northern part of Southeast Reef.

The island northeast of Fort Jefferson called Hospital Key (Fig. 10) was once called Sand Key. It received its new name when a small wooden quarantine/hospital was built there in 1861 before the yellow-fever epidemic in 1867. The hospital, built on a brick foundation, was destroyed by a hurricane, and red bricks are still scattered around the much-reduced sand island. Huge blocks of beachrock have been submerged 2 to 3 m below sea level around the south side of the key. The names of Bush Key and adjoining Long Key have often been interchanged since the first maps were made. Bush Key, the key connected to Garden Key before Hurricane Katrina in 2005, is often misnamed Bird Key, probably because it is the nesting site for thousands of sooty terns.

Loggerhead Key, the lighthouse, and the Carnegie Institution Laboratory

The largest, and certainly the longest, sandy key is Loggerhead Key in the western Tortugas (Figs. 10, **15A, B**). The prominent 46-m-high (150 ft) lighthouse was built there because of ship groundings, loss of cargo, and strategic location. The light was completed in 1858 to replace the smaller one on Garden Key that had existed since 1826 (Dean, 1992). Construction of Fort Jefferson began in 1846. The fort was built around the lighthouse on Garden Key, while the light was still in operation. Loggerhead lighthouse has had various forms of illumination since its initial construction. The most elaborate was a fresnel lens powered by electricity that began operation in 1933. The heavy cluster of lenses floated on a pool of mercury and was turned by weights and a pulley system in the center of the lighthouse structure. In 1986, the complicated lens was replaced with a more modern electric "aero beacon." It flashes every 20 seconds and can be seen for 30 km on clear nights (Dean, 1992).

Loggerhead Key was owned by the Lighthouse Service (Department of Commerce), which became the U.S. Coast Guard (Department of Transportation) in 1939 just before World War II. The Coast Guard still maintains the lighthouse but has turned the property over to the National Park Service. It was from the Lighthouse Service that the Carnegie Institution, funded by multi-millionaire steel magnate Andrew Carnegie, obtained a lease to property on the north end of the island for the construction of a small research laboratory. Construction began in 1904, under the direction of Alfred Goldsboro Mayor.* Mayor had been a student of Alexander Agassiz and having traveled the world extensively with Agassiz, was well qualified to pick this site for a tropical research station (**Fig. 16**). He laid the groundwork for the station in an article in the journal *Science* in 1903 (Mayer, 1903). His model was the famous Stazione Zoologica Marine Laboratory on the Mediterranean in Naples, Italy.

The first researchers arrived in the summer of 1905. Mayor's 1905 advertisement for senior researchers to work at the laboratory is reproduced in the Appendix. In spite of its remote location, lack of many amenities, and near destruction of the laboratory by hurricanes in 1910 and 1919, approximately 146 different researchers worked there between 1905 and 1939 (Colin, 1980). Schmidt and Pikula

* Mayor changed the spelling of his name from Mayer to Mayor during World War I because of rising anti-German sentiment.

Figure 15. (A) Oblique aerial photograph of Loggerhead Key looking southeast. Carnegie Laboratory was located near north tip of island. Note ribbon of beachrock extending northward just off the island (at left of photo) and the spits at both ends of the island that constantly shift position during storms. (B) Oblique view of Loggerhead Key looking southward shows the lighthouse, light keeper's quarters, loading dock at left, and boat house near beach at right. The Carnegie Laboratory was located at the bottom of the photo. Arrow indicates Mayor's monument. Beachrock that forms rapidly and protects the island from erosion can be seen along west side of the island to the right.

Figure 16. Photograph of laboratory and sleeping quarters as they looked in 1905. Photograph is from Schmidt and Pikula (1997).

(1997) annotated a valuable bibliography of scientific studies conducted here. In addition to Mayor's advertisement for researchers, the Appendix also contains five tributes to the quality and far-reaching effects of research conducted here. The tributes were prepared by prominent researchers in the disciplines that blossomed at the Carnegie Laboratory. Also in the Appendix is a selection of photographs of the facility, researchers at work, their vessels, and unique underwater photographs. The photographs taken here in 1917 were the world's first underwater photographs of marine life made by a diver.

As you walk past the lighthouse and its cisterns, the light keeper's dwellings, generator shed, and an old boathouse, continue on to the beach just west of the light and walk northward from there to the Carnegie Laboratory site.

Beachrock

One of the first features you will notice upon reaching the west shore is a ribbon of rock paralleling the beach (**Fig. 17A, B**). Beachrock here was studied by Vaughan (1914b), Daly (1924), and Field (1919, 1920). Vaughan had mentioned that beachrock at Loggerhead Key was up to "8 ft" thick. Although that thickness could exist, recent investigators have not found the beachrock to be more than 1 m thick. Ginsburg (1953) described the composition of this beachrock and pointed out that its formation is controlled by the extent of tidal fluctuation. Multer (1971) examined it and came to similar conclusions. Any beachrock >2 m thick would thus be below the present tidal range and therefore must have formed when sea level was lower (Ginsburg, 1953). Drowned beachrock that formed during a lower stand of sea level is not uncommon in the Bahamas

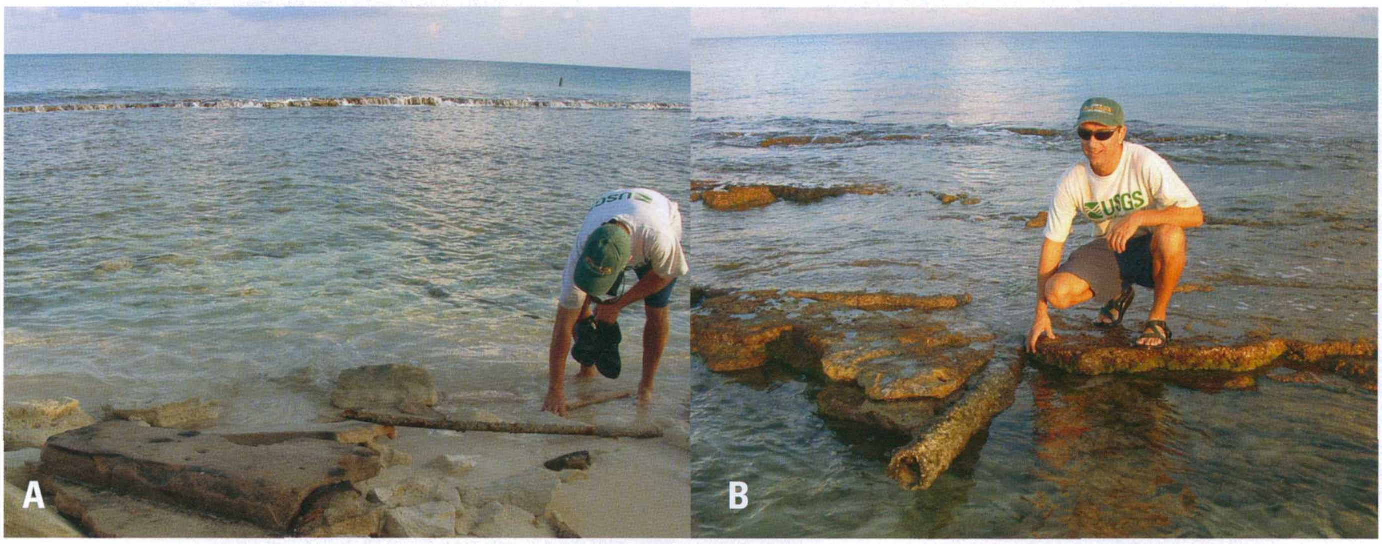


Figure 17. (A) View on west side of island showing beachrock offshore from site of the Carnegie Laboratory dock. Note vertical iron mooring pole in background and remnants of cement laboratory foundation in foreground. In 1976, beach sand extended seaward and covered the beachrock in the background. (B) The iron pipe (sewer or seawater intake?) is now part of the beachrock and attests to its rapid formation.

(Shinn, 1978) and can be observed nearby at Hospital Key.

Except for the beachrock, the island is composed entirely of uncemented carbonate sand and coral fragments (referred to as detritus by Vaughan, 1914b). **Figure 18** shows some common carbonate sand "detritus" producers. An exploratory core drilled in 1976 on the beach opposite the laboratory site (**Fig. 19**) at the north end of the island penetrated beachrock before encountering about 15 m of carbonate sand and coral. In that core, the consolidated Pleistocene limestone was encountered at 16 m below sea level, thus indicating the rapid rate of reef and island growth during Holocene sea-level rise. Since that core was drilled, hurricanes and winter storms have removed the beach sand at the core site, and the northward-extending beachrock is now well exposed (Fig. 17A, B). A small strip of submerged eastward-dipping beachrock can also be found off the north tip of the island. The eastward dip of this rock preserves the original dip of the beach on the east side of the island, providing additional evidence that the island once extended well beyond its present position.

West of the laboratory site, a recent storm has exposed an iron pipe (seawater intake or sewage outfall?) imbedded in (pre-dating?) the beachrock (Fig. 17B). It is believed that the pipe was laid in soft sand when the laboratory was built. If confirmed, this portion of beachrock formed after construction of the laboratory and thus demonstrates the rapidity of beachrock formation. Mayor reported to Daly that sand deposited here by a hurricane in 1919 became beachrock in one year (Daly, 1924).

It is apparent that this rapid rock-forming process has played a major role in the preservation of Loggerhead Key. Had the rock not continually formed and created a natural breakwater/seawall, this island, its flora and fauna, including the site of the Carnegie Laboratory, might have disappeared long ago. This is an arresting example of the interplay

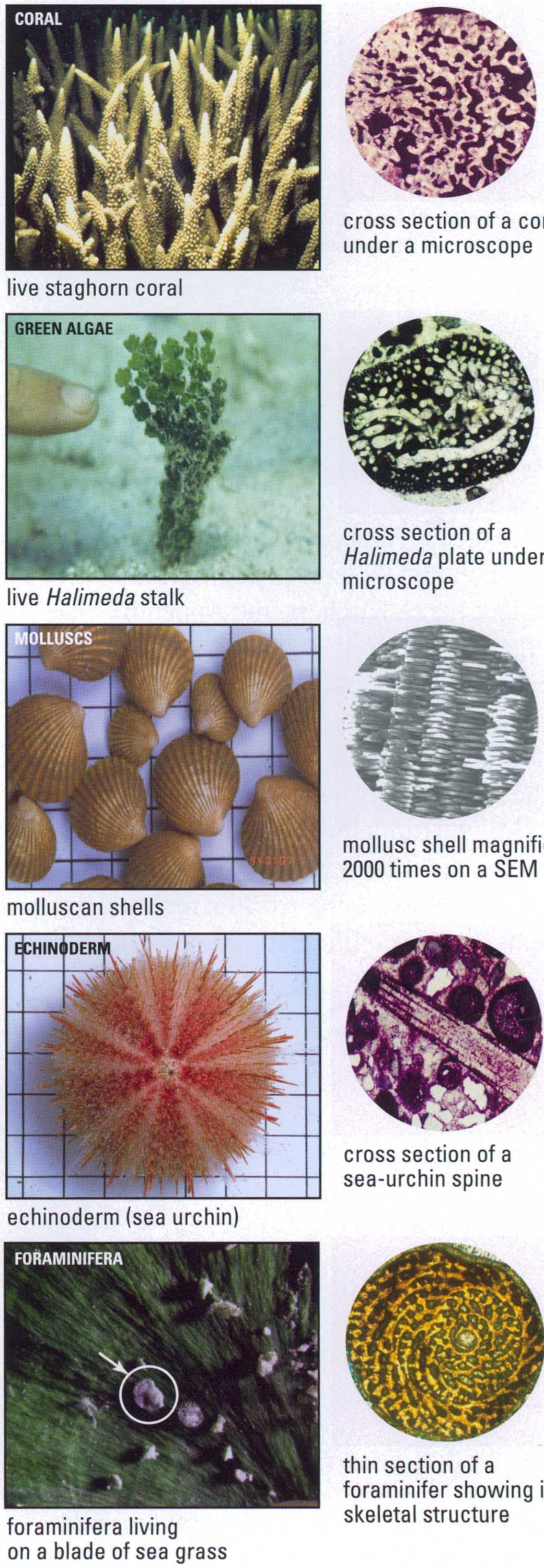


Figure 18. Common organisms that produce the carbonate sand (called "detritus" by early researchers at the laboratory).

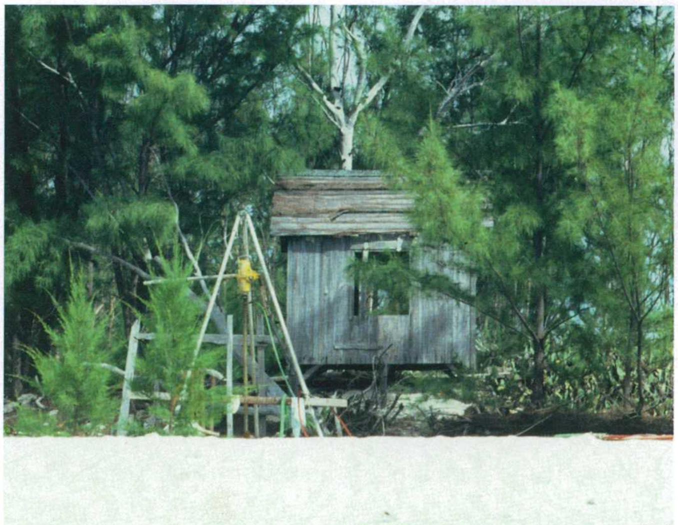


Figure 19. USGS coring tripod set up on beach in 1976 in approximate position of the Carnegie Laboratory dock. Wood shack in background (no longer present) may have been part of laboratory. Sand in foreground covered the beachrock shown in Figure 17A, B.

between geology and biology. It is a place where scientific disciplines merge.

Another feature to note about beachrock is the way it breaks naturally to form large blocks. Such blocks, especially where submerged by rising sea level, can have a decidedly "man-made" look, like an old broken concrete sidewalk or road, and indeed, "alternative thinkers" have proclaimed many examples to be the work of ancient man, aliens, and in some cases such as off Bimini in the Bahamas, Atlantians (Shinn, 1978, 2004).

The cement between sand grains, laminations created by grain-size variations as described by Ginsburg (1953), and meniscus cement and keystone vugs created by air bubbles (Dunham, 1970, 1971) provide clues for distinguishing beachrock from freshwater-cemented limestone (see Fig. 2) and from rocks formed under permanent marine conditions.

Mayor's vision, the Laboratory

Little remains of the Tortugas Laboratory, and even the foundations are no longer visible. Erection of prefabricated buildings began in 1904. In 1905, there were two main buildings, serving as dormitory and laboratory (Fig. 16). A separate building served for alcohol (preservative) storage. There were also a machine shop and a dock house. A windmill pumped seawater and aeriated aquaria. The remains of a cement seawater tank and shards of aquarium glass are the most visible remnants today.

Mayor was extremely productive and published hundreds of papers (see Davenport, 1926). Many of his papers were on medusae, and he personally edited papers from the Tortugas Laboratory until his untimely death. In terms of reef building, the two most notable were on temperature tolerance of corals and other marine organisms (Mayer, 1914, 1918).

In 1976, a decaying shack that may have been part of the laboratory complex (shown in Fig. 19) still existed when the core was drilled on the beach. There was no trace of the loading dock, and only an iron mooring pole (still visible) remains just offshore. Recent hurricane erosion has uncovered some railroad rails, suggesting either a small rail-car connection with the lighthouse, loading dock, or a "marine ways" to bring boats ashore for repairs.

Mayor dies at Loggerhead Key, 1922

Just south of the site is a "must see" memorial plaque designed by Mayor's artist wife. The monument was erected in 1923, a year after Mayor fainted and expired alone on the beach near the laboratory. Mayor had recently returned from Arizona where he had spent several months recuperating from tuberculosis.

Figure 20. The Mayor monument as it stood near the laboratory ruins in 2004. Note that invasive *Casuarina* trees (visible in Fig. 19) have been removed from the entire island. The trees infested the island mainly after 1940. The monument was placed here in 1923, the year after Mayor expired on the beach near the laboratory.

The inspirational monument shown in **Figure 20** reads:

ALFRED GOLDSBORO MAYOR WHO STUDIED THE BIOLOGY OF MANY SEAS AND HERE FOUNDED A LABORATORY FOR RESEARCH FOR THE CARNEGIE INSTITUTION DIRECTING IT FOR XVIII YEARS WITH CONSPICUOUS SUCCESS BRILLIANT VERSATILE COURAGEOUS UTTERLY FORGETFUL OF SELF HE WAS THE BELOVED LEADER OF ALL THOSE WHO WORKED WITH HIM AND WHO ERECT THIS TO HIS MEMORY BORN MDCCCLXVIII DIED MCMXXII

A new beginning and the beginning of the end

William H. Longley was appointed Executive Director of the laboratory following Mayor's death. He directed the laboratory until his death in 1937. Longley specialized in systematics and behavior of tropical Atlantic fishes. Using a diving helmet, he began experimentation with underwater photography in 1917 to record color changes in fishes.* In 1926, with National Geographic photographer Charles Martin, Longley and Samuel F. Hildebrand took the first successful color underwater photographs off the beach near the laboratory. Some of the original photographs are reproduced in the Appendix.

Longley died in 1937 before finishing his book on tropical Atlantic fishes. The book was completed by Hildebrand in 1941 (Longley and Hildebrand, 1941). See the tribute to his research by C. Richard Robins in the Appendix.

After Longley's death David Tennent became the laboratory administrator until the lab closed in 1939 for economic reasons, just before the outbreak of World War II. Tennant had worked at the lab since 1909, principally on sea urchin embryology.

Reflections

The beginning of World War II, economics, and a shift in interest toward molecular biology led to the abrupt closing of the laboratory in 1939 (Colin, 1980). Interestingly, of the approximately 146 researchers who worked here from 1905 to 1939, no women were invited to work at the laboratory (Colin, 1980).

It should be noted that during the existence of the Carnegie Laboratory, corals flourished just off the beach on both sides of Loggerhead Key. The area

*A premature ignition of magnesium flash powder temporarily blinded Longley, who was put out of commission for several days.

west of the island, now called Little Africa, was used for experimentation and collection of marine specimens. Coral growth-rate experiments were conducted by Vaughan just west of the island as well as in the moat of Fort Jefferson at Garden Key. At that time, corals grew within the moat, so work could be accomplished in the safety of shallow water. For deeper-water collecting and dredging, the various motor launches and skiffs were fitted with winches and reels of wire.

The laboratory operated several research vessels and skiffs between 1905 and 1939. The first research vessel was the 18-m (60-ft) ketch-rigged *Physalia* built in East Booth Bay, Maine, in 1904. By 1910, the *Physalia*, which had a 20-hp auxiliary engine, suffered extreme wood rot and was replaced in 1911 by the 21-m (70-ft) twin-screw *Anton Dohrn*, built in Miami, Florida (Davenport, 1926). It was the largest vessel ever constructed in South Florida at that time. Photographs of the *Anton Dorn* are shown in the Appendix.

At this point in your tour, you may either wander the island at your leisure to observe flora and fauna, or if prepared, you may snorkel off the beach. Around noon (and upon a horn signal from the boat), you should return to the boat and be transported to Fort Jefferson for a guided cultural tour of the fort. Lunch will be served at Fort Jefferson.

Section III

Biology: the research continues in 2005

Biology was the primary subject area at Dry Tortugas during the Carnegie era. The Carnegie workers focused on animal physiology, distribution and abundance of organisms, taxonomy of many different groups of plants and animals, embryology, heredity, evolution, animal psychology, chemistry of sea water, coloration of reef fishes, habits of sea gulls, and memory in fishes, to name a few studies. Some of this work is remarkable for the test of time. Vaughan's coral growth-rate studies and Mayor's thermal-tolerance experiments are examples of the high quality of their work. A selected list of biological publications follows.

Selected literature

Carey, L.R., 1918, The Gorgonaceae as a factor in the formation of coral reefs: Papers of the Tortugas Laboratory, v. 9, p. 341-362.

Clarke, L.B., and Hess, W.N., 1942, Swarming of the Atlantic palolo worm *Leodice fucata* (Ehlers): Carnegie Institution of Washington Publication 33, p. 21-70.

DeLaubenfels, M.W., 1936, A discussion of the sponge fauna of the Dry Tortugas in particular and the West Indies in general, with material for the revision of families and orders of the Porifera: Carnegie Institution of Washington Publication 467, no. 30, 225 pp.

Longley, W.H., and Hildebrant, S.F., 1941, Systematic catalog of the fishes of Tortugas, Florida, with observations on the color, habits, and local distribution: Papers of the Tortugas Laboratory, v. 34, 331 pp.

Matthai, G., 1916, Preliminary report on the comparative morphology of the recent Madreporaria around Tortugas: Carnegie Institution of Washington Yearbook 14, 209 pp.

Mayer, A.G., 1903, The Tortugas, Florida as a station for research in biology: Science, v. 17, p. 190-192.

Mayer, A.G., 1914, The effects of temperature on tropical marine organisms: Carnegie Institution of Washington Publication 183, p. 3-24.

Taylor, W.M., 1928, The marine algae of Florida with special reference to the Dry Tortugas: Carnegie Institution of Washington Publication 379, 219 pp.

Vaughan, T.W., 1914, The building of the Marquesas and Tortugas atolls and a sketch of the geologic history of the Florida reef tract: Carnegie Institution of Washington Publication 182, p. 55-67.

Vaughan, T.W., 1915, Growth rate of the Floridian and Bahamian shoal-water corals: Carnegie Institution of Washington Yearbook 13, p. 221-231.

Watson, J.B., 1908, The behavior of noddy and sooty terns: Carnegie Institution of Washington Publication 103, p. 187-255.

Wells, J.W., 1932, Study of the reef corals of the Dry Tortugas: Carnegie Institution of Washington Yearbook 31, 290 pp.

Yonge, C.M., 1937, The effects of mucus on oxygen consumption: Carnegie Institution of Washington Publication 475, p. 209-214.

Modern research

Research efforts in recent years have been of high quality but have not equaled the quantity of that performed when the Carnegie Laboratory was in operation. In recent years, most biological and geological research, by necessity, has been limited to short expeditions seldom lasting more than a week or two at a time. Oceanographers have conducted their work from larger vessels and do not need to go ashore to tabulate and interpret their data. The first multidisciplinary research effort at Dry Tortugas since the closing of the Carnegie Laboratory was called TRACTS 1 and 2 (Tortugas Reef Atoll Continuing Transect Study) in 1975 and 1976. The expeditions were organized by Gary Hendrix, then Director of the NPS research lab in Everglades National Park, and Gary Davis, also of that laboratory. They assembled a group of researchers and housed them within Fort Jefferson for a month of research. The TRACTS concept was in part to revive interest in establishing a research facility similar to the Carnegie effort. That dream lives on today.

Current research is focused on fisheries, oceanographic processes, taxonomy, ecological relationships, ornithology, phycology, coral diseases, turtle nesting, sponges, sharks, resource management, and multidisciplinary studies. Work has been funded by the National Park Service, NOAA's National Undersea Research Program (NURC), the Florida Keys National Marine Sanctuary (FKNMS), the U.S. Environmental Protection Agency (EPA), National Science Foundation (NSF), private institutions, and by the State of Florida. Researchers are from academic, government, and private institutions.

Benthic coral reef work from TRACTS 1 and 2 (Jaap et al., 1989) provided a 1975/1976 baseline and important information on the abundance and species richness of the Scleractinia. Dry Tortugas

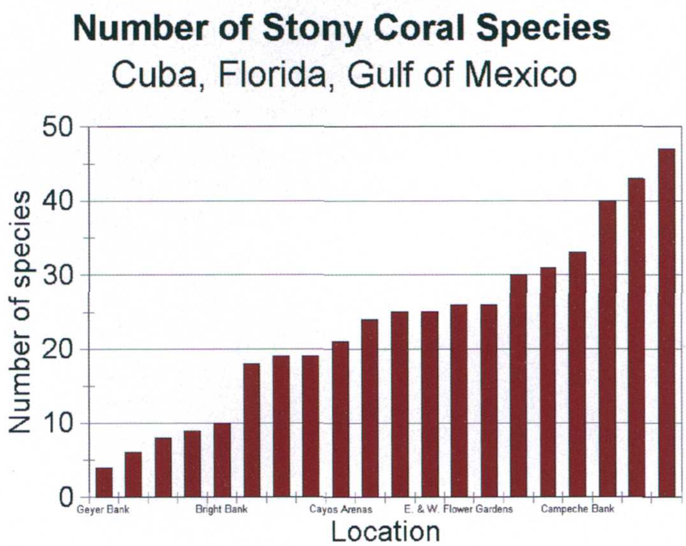


Figure 21. The number of coral species at Tortugas equals the highest values shown in this tabulation.

exceeds all other Gulf of Mexico reefs in the number of coral species that occur on a reef (**Fig. 21**).

The Department of Natural Resources (DNR), Department of Environmental Protection (DEP), and the Fish and Wildlife Commission (FWC) produced multiple coral reef benthic-resource reports of the Dry Tortugas (Jaap et al., 1991, 2000, 2002a, 2002b; Jaap and Sargent, 1993). A list of Scleractinia and *Millepora* species known from the Dry Tortugas is provided in the Appendix. In 1999, the U.S. EPA/NOAA-sponsored Coral Reef Evaluation and Monitoring Project (CREMP) was expanded with the inclusion of three sites (12 stations) in the two Tortugas Ecological Reserves and in the Dry Tortugas National Park (DTNP).

Over the past 30 years, coral communities in the Dry Tortugas have been relatively stable (Jaap et al., 2002a, 2002b); however, some major losses have occurred. As mentioned earlier, elkhorn-coral (*Acropora palmata*) assemblages have virtually disappeared from the area (Davis, 1982; Jaap and Sargent, 1993). Staghorn (*Acropora cervicornis* and *A. prolifera*) populations have collapsed since 1981. More recently, the CREMP has documented a decrease of mean percent stony-coral cover between 2001 and 2003. This decrease was largely attributed to losses in two stony-coral species, *Montastraea annularis* complex and *Colpophyllia natans*, and is most likely attributed to an unknown coral disease. Although the Dry Tortugas reefs are some of the most unique and pristine reefs off southern Florida, increased numbers of visitors require a greater vigilance for their safety and management. Monitoring at Tortugas is currently focused on five major areas, shown in **Table 1**.

Location of monitoring stations is shown in **Figure 22**. The numbers of species at the Tortugas sites compared with those of the Florida Keys are shown in **Figure 23**. Location of these sites is shown in Figure 22. Observational data from these sites are shown in **Figures** 22, 23, **24**, **25**, and **26**.

The mean number of species is greater at the Tortugas monitoring sites than at other sites in the Florida Keys and southeast Florida (Fig. 24), and the number of species here is as high as anywhere in the Caribbean (Fig. 21). These high numbers are to be expected because of the more southerly location and remoteness of the Tortugas from direct anthropogenic influences.

The percent cover of octocorals does not parallel that of stony corals. Octocoral cover is generally high where coral cover is low and vice versa. Of course, there are numerous data pertaining to other organisms, including invertebrates, fishes, sharks, birds, turtles, plants, etc., that are beyond the scope of this guide.

Site Name	Number of Stations	Max Depth (m)	Latitude (N)	Longitude (W)
Bird Key Reef (BK)	4	12.5	24 36.703	82 52.212
Mike's Peak (MP)	4	8.9	24 36.480	82 56.644
Temptation Rock (TR)	4	9.7	24 38.587	82 55.844
White Shoal (WS)	4	8.2	24 38.484	82 53.769
Palmata Patch (PAL)	2	2.5	24 37.243	82 52.042
Prolifera Patch (PRO)	3	2.0	24 37.239	82 52.180

Table 1. Latitude, longitude, number of stations, and maximum depth for long-term monitoring sites at Dry Tortugas National Park.

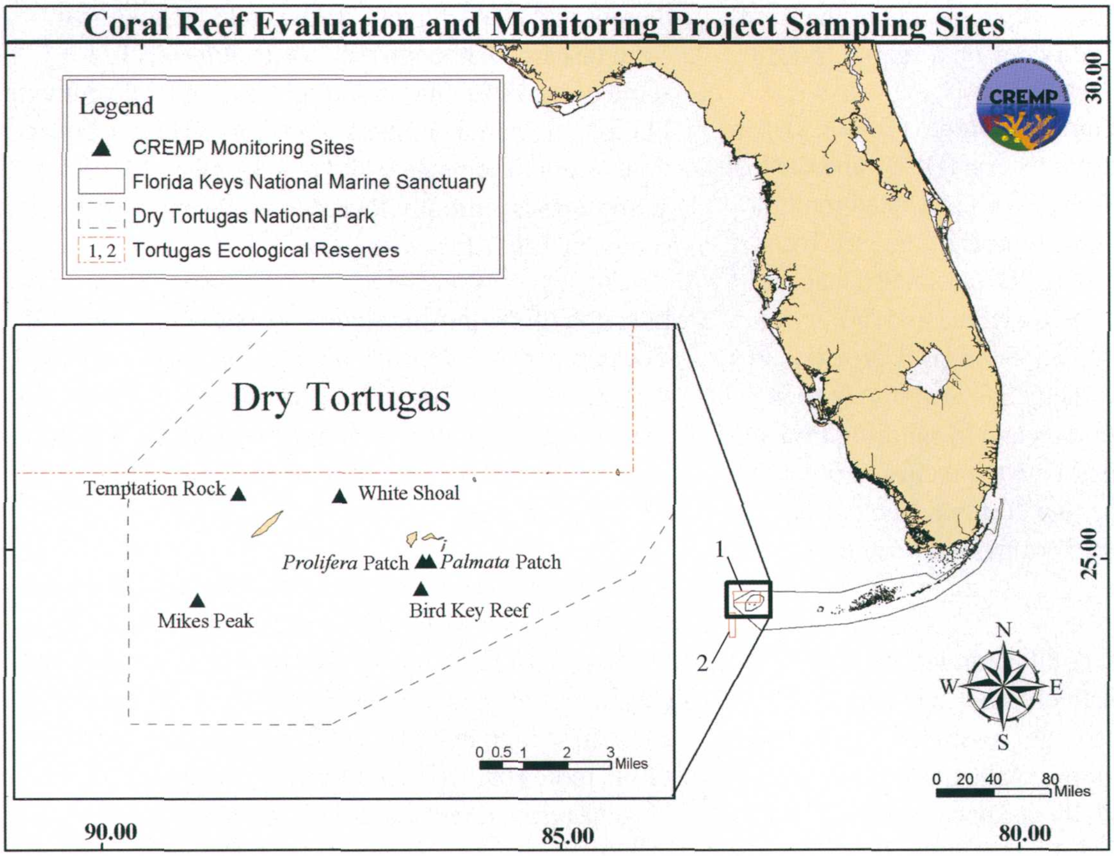


Figure 22. Location of monitoring sites in Dry Tortugas National Park. Note Tortugas Ecological Reserves North and South (1, 2) are part of the park.

In addition, NPS scientists with the South Florida/ Caribbean Network, Inventory and Monitoring Program (SFCN-I&M) have developed a new protocol that involves filming random transects in selected study areas. The study area is within the TRACTS 1 line, and fixed quadrants were initiated by the (then) FMRI

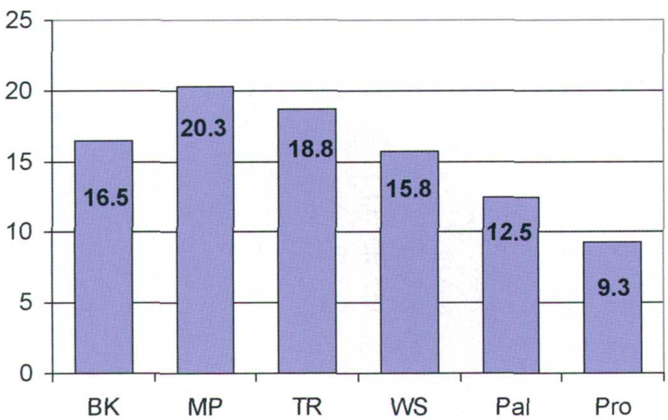


Figure 23. Mean number of stony-coral species per station for NPS Dry Tortugas monitoring sites in 2004. BK = Bird Key, MP = Mike's Peak, TR = Temptation Rock, WS = White Shoal, Pal = *Palmata* Patch, Pro = *Prolifera* Patch.

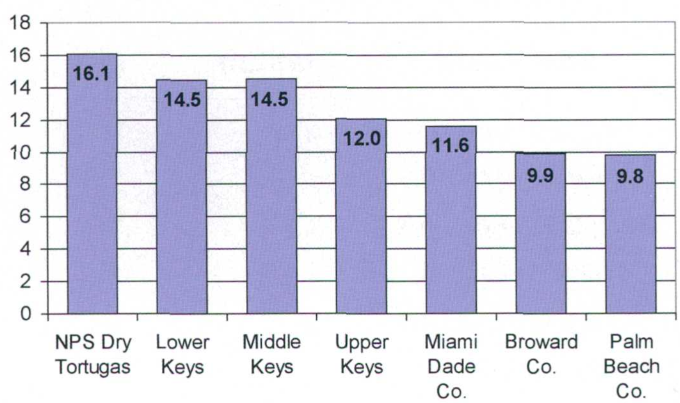


Figure 24. Mean number of stony-coral species per station by region in 2004.

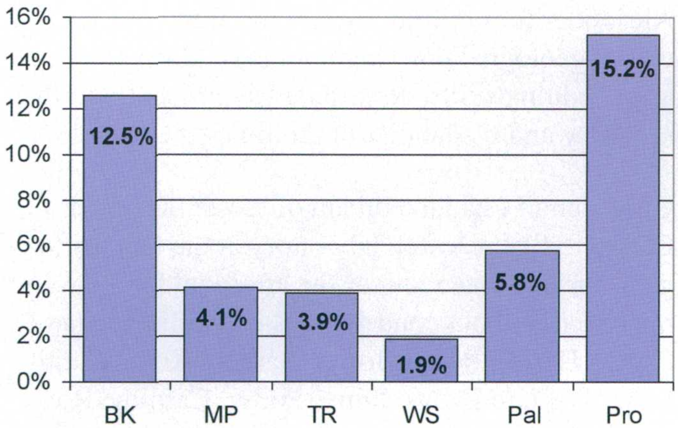


Figure 25. Percent coral cover at the sites shown in Figure 2. Note that site Pro is in Five Foot Channel and is the same *Acropora prolifera* area described by Vaughan (1910).

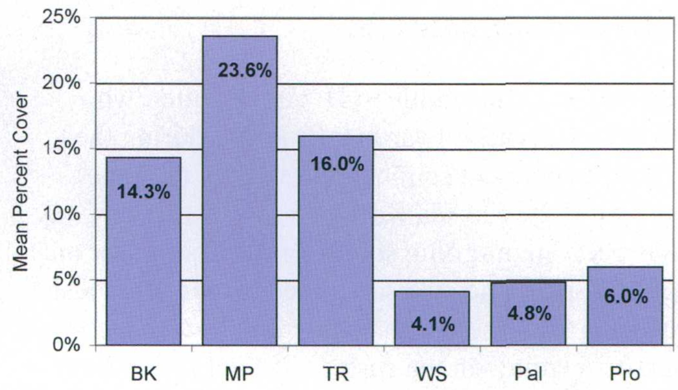


Figure 26. Mean percent octocoral-coral cover for NPS Dry Tortugas monitoring sites in 2004. BK = Bird Key, MP = Mike's Peak, TR = Temptation Rock, WS = White Shoal, Pal = *Palmata* Patch, Pro = *Prolifera* Patch.

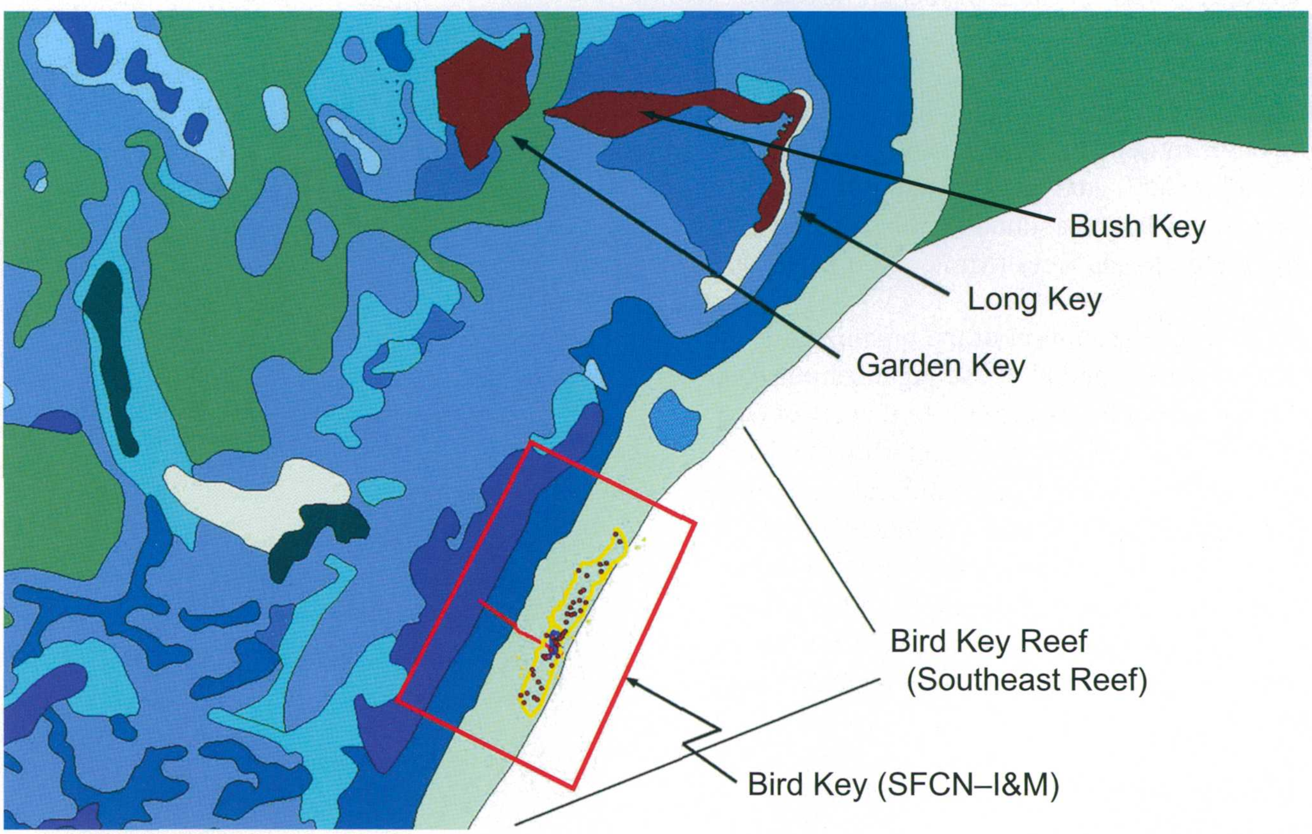


Figure 27. The locations of study sites at Bird Key/Southeast Reef.

at Bird Key Reef (also called Southeast Reef or Long Key Reef). The location of these study sites is shown in **Figure 27**. Data from the study and the coral data depicted in the above graphs will be discussed in a presentation in Key West.

Acknowledgments:

We dedicate this guide to H. Gray Multer, who teamed up with Edward Hoffmeister during the 1960s to conduct seminal research on the limestones of the Florida Keys and Dry Tortugas. Gray has been an on-going source of inspiration for one of us (EAS) since we scrambled through the bushes investigating the origin of the red/brown caliche crusts forming on the surface of the Florida Keys. Little did we know in the early 1960s that we were seeing the signature of transoceanic African dust. Gray's understanding of how the crusts formed played a significant role in interpreting the origin of Pleistocene crusts. Because of this knowledge, the crusts became standard markers for stratigraphic correlation within not only subsurface limestones of South Florida but also the geologic record in general. After retirement, Gray returned to South Florida, and in 2000, and with the aid of a suite of new cores, published a landmark paper on the stratigraphy of the Florida Keys (Multer et al., 2002).

We acknowledge the support of the organizing committee members and all those organizations and individuals who contributed funds to this effort (see list on inside cover). Karilyn B. Jaap is especially acknowledged for having located difficult-to-find Carnegie-related literature and old photographs. We thank historian Lester Stephens for insights into the life of Mayor and for old photographs of the laboratory and boats. We thank Brantz and Ana Mayor for the frontispiece photograph of Alfred Goldsborough Mayor.

Matt Patterson, Jeff Miller, and Mike Ryan provided critical information regarding NPS programs and disappearing islands. We acknowledge John Brock and his LIDAR team for the cover image of Dry Tortugas. We especially thank digital artist Betsy Boynton for preparation of all illustrations and conversion of text for publication, and Llyn French for shepherding the guide through the printing process. We thank Christina Kellogg and John Alexander for preliminary editing. Barbara Lidz, whose geologic knowledge of the fieldtrip area and astute editing skills, contributed significantly to the accuracy and readability of the final text.

Gary Hendrix had the dream of reestablishing a Carnegie-like research laboratory at the Dry Tortugas. Our understanding of the area could not have happened without contributions of Phillip Dustan, Robert Halley, Robert Jones, Barbara Kojis, Judith Lang, William Lyons, James Porter, Caroline Rogers, Karen Steidinger, James Tilmant, and Jennifer Wheaton. Field partners at Dry Tortugas included Kelly Donnelly, Roy Gaensslen, Cliff Green, Keith Hackett, Peter Hood, Harold Hudson, Joe Kimmel, Selena Kupfner, Matthew Lybolt, Ronny Matchok, Leann Miller, Daniel Robbin, Linda Vandaman, and many others too numerous to mention.

References

Agassiz, A., 1883, Explorations of the surface fauna of the Gulf Stream, under the auspices of the United States Coast Survey, II. The Tortugas and Florida reefs: Memoirs of the American Academy of Arts and Sciences, Centennial Volume II, p. 107-132.

Barnette, M.C., 2003, Shipwrecks of the sunshine state: Florida's submerged history: Association of Underwater Explorers, 195 pp.

Colin, P.L., 1980, A brief history of the Tortugas Marine Laboratory and the Department of Marine Biology, Carnegie Institution of Washington, *in* Sears, M., and Merriman, D., eds., Oceanography: The Past: Springer-Verlag, p. 138-147.

Daly, R.A., 1924, The geology of American Samoa: Carnegie Institution of Washington Publication 340, p. 93-143.

Davenport, C.B., 1926, Alfred Goldsborough Mayor, Biography: Memoirs of the National Academy of Science, v. 21, no. 8, p. 1-8.

Davis, G.E., 1979, Outer continental shelf resource management map, coral distribution Fort Jefferson National Monument, the Dry Tortugas: U.S. Department of the Interior, Bureau of Land Management, Outer Continental Shelf Office, 500 Camp Street, New Orleans, La. 70130.

Davis, G.E., 1982, A century of natural change in coral distribution at the Dry Tortugas: A comparison of reef maps from 1881 and 1976: Bulletin of Marine Science, v. 32, no. 2, p. 608-623.

Dean, L., 1992, Lighthouses of the Florida Keys: Historic Florida Keys Foundation, Key West, Florida, 197 pp.

Dobbs, D., 2005, Reef madness: Charles Darwin, Alexander Agassiz, and the meaning of coral: Pantheon Books, New York, 306 pp.

Dunham, R.J., 1970, Keystone vugs in carbonate beach deposits (abstract): American Association of Petroleum Geologists Bulletin, v. 54, p. 845.

Dunham, R.J., 1971, Meniscus cement, *in* Bricker, O.P., ed., Carbonate Cements: Johns Hopkins University Studies in Geology, no. 19, p. 297-300.

Dustan, P., Lidz, B.H., and Shinn, E.A., 1991, Impact of exploratory wells, offshore Florida: A biological assessment: Bulletin of Marine Science, v. 48, no. 1, p. 94-124.

Field, R.M., 1919, Investigations regarding the calcium carbonate oozes at Tortugas, and the beachrock at Loggerhead Key: Carnegie Institution of Washington Yearbook, no. 18, p. 197-198.

Field, R.M., 1920, Origin of beachrock (coquina) at Loggerhead Key, Tortugas (abstract): Geological Society of America Bulletin, v. 31, p. 215.

Gallagher, D., Causey, B.D., Gato, J., and John Viele, J., 1997, The Florida Keys Environmental Story, a Panorama of the Environment, Culture and History of Monroe County, Florida: Seacamp Association, Inc., publisher, Big Pine Key, Fla., 371 pp.

Ginsburg, R.N., 1953, Beachrock in south Florida: Journal of Sedimentary Petrology, v. 23, no. 2, p. 85-92.

Halley, R.B., and Evans, C.E., 1983, The Miami Limestone, A Guide to Selected Outcrops and Their Interpretation (with a Discussion of Diagenesis in the Formation): Miami Geological Society, Miami, Fla., 65 pp.

Hoffmeister, J.E., Stockman, K.W., and Multer, H.G., 1967, Miami Limestone of Florida and its Recent Bahamian counterpart: Geological Society of America Bulletin, v. 78, p. 175-190.

Hudson, J.H., 1985, Growth rate and carbonate production in *Halimeda opuntia*, Marquesas Keys, Florida, *in* Toomey, D.F., and Nitechi, M.H., eds., Paleoalgology: Contemporary Research and Applications: Springer-Verlag, Berlin, Heidelberg, p. 257-263.

Hurley, N.E., 1994, Lighthouses of the Dry Tortugas, An Illustrated History: Historic Lighthouse Publishers, Aiea, Hawaii, 80 pp.

Jaap, W.C., Lyons, W.G., Dustan, P., and Halas, J.C., 1989, Stony coral (Scleractinia and Milleporina) community structure at Bird Key Reef, Ft. Jefferson National Monument, Dry Tortugas, Florida: Florida Marine Research Publication, v. 46, 31 pp.

Jaap, W.C., Mallison, D., Hine, A., Muller, P., Jarrett, B., and Wheaton, J., 2000, Deep reef communities: Tortugas Banks and Pulley Ridge: First International Symposium on Deep Sea Corals, Halifax, Nova Scotia, p. 12-13.

Jaap, W.C., and Sargent, F.J., 1993, The status of the remnant population of *Acropora palmata* (Lamarck, 1816) at Dry Tortugas National Park, Florida, with a discussion of possible causes of changes since 1881: Proceedings of the Colloquium on Global Aspects of Coral Reefs: Hazards and History: University of Miami, Fla., p. 101-105.

Jaap, W.C., Wheaton, J.L, and Donnelly, K.B., 1991, A three-year evaluation of community dynamics of coral reefs at Fort Jefferson National Monument (Dry Tortugas National Park), Dry Tortugas, Florida: Florida Marine Research Institute Report, 23 pp.

Jaap, W.C., Wheaton, J.L., Hackett, K.E., Callahan, M.K., Kupfner, S., Kidney, J., and Lybolt, M., 2002b, Long-term (1989-present) monitoring of selected coral reef sites at Dry Tortugas National Park: Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute Report, 43 pp.

Jaap, W.C., Wheaton, J.L., Schmahl, G., and Forqurean, J., 2002a, Dry Tortugas benthic community characterization: Florida Marine Research Institute Report, 22 pp.

Lessios, H.Q., Robertson, D.R., and Cubit, J.E., 1984, Spread of *Diadema* mass mortalities through the Caribbean: Science, v. 226, p. 335-337.

Lidz, B.H., Hine, A.C., Shinn, E.A., and Kindinger, J.L., 1991, Multiple outer-reef tracts along the South Florida bank margin: Outlier reefs, a new windward-margin model: Geology, v. 19, p. 115-118.

Lidz, B.H., Reich, C.D., Peterson, R.L., and Shinn, E.A., 2006, New maps, new information: Coral reefs of the Florida Keys: Journal of Coastal Research, v. 22, no. 2, p. 61-83.

Lidz, B.H., Reich, C.D., and Shinn, E.A., 2003, Regional Quaternary submarine geomorphology in the Florida Keys: Geological Society of America Bulletin, v. 115, no. 7, p. 845-866, plus oversize color plate of Pleistocene topographic and Holocene isopach maps.

Lidz, B.H., Reich, C.D., and Shinn, E.A., 2005, Systematic mapping of bedrock and habitats along the Florida reef tract: Central Key Largo to Halfmoon Shoal (Gulf of Mexico): U.S. Geological Survey Professional Paper 1714 (DVD-ROM).

Longley, W.H., and Hildebrand, S.F., 1941, Systematic catalogue of the fishes of Tortugas, Florida, with observations on color, habits, and local distribution: Papers of the Tortugas Laboratory, v. 34, p. 1-331.

Mallinson, D., Hine, A.C., Hallock, P., Locker, S., Shinn, E.A., Naar, D., Donahue, B., and Weaver, D., 2003, Development of small carbonate banks on the south Florida platform margin: Response to sea level and climate change: Marine Geology, v. 199, p. 45-63.

Mayer, A.G., 1903, The Tortugas, Florida, as a station for research in biology: Science, v. 17, no. 422, p. 190-192.

Mayer, A.G., 1914, The effects of temperature on tropical marine organisms: Carnegie Institution of Washington Publication 183, p. 3-24.

Mayer, A.G., 1918, Toxic effects due to high temperature: Carnegie Institution of Washington Publication 252, p. 175-178.

Multer, H.G., 1971, Holocene cementation of skeletal grains into beachrock, Dry Tortugas, Florida, *in* Bricker, O.P., ed., Carbonate Cements: Johns Hopkins University Studies in Geology, no. 19, p. 25-26.

Multer, H.G., Gischler, E., Lundberg, J., Simmons, K.R., and Shinn, E.A., 2002, Key Largo Limestone revisited: Pleistocene shelf-edge facies, Florida Keys, USA: Facies, v. 46, p. 229-272.

Parks, P., 1968, The Railroad that Died at Sea, Florida East Coast Railway Flagler System, the Florida East Coast's Key West Extension: Langley Press, Inc., Key West, Fla., 48 pp.

Porter, J.W., Battey, J.F., and Smith, J.G., 1982, Perturbation and change in coral reef communities: Proceedings of the National Academy of Science, v. 79, p. 1678-1681.

Sanford, S., 1909, The topography and geology of southern Florida: Florida Geological Survey Second Annual Report, p. 175-231.

Schmidt, T.W., and Pikula, L., 1997, Scientific studies on Dry Tortugas National Park: An annotated bibliography: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Interior, National Park Service, 108 pp.

Shinn, E.A., 1978, Atlantis: Bimini's hoax: Sea Frontiers, v. 14, p. 130-141.

Shinn, E.A., 2004, Geologists, beachrock and Atlantis: Adventures with true believers: Skeptical Inquirer, v. 28, no. 1, p. 38-44.

Shinn, E.A., Hudson, J.H., Halley, R.B., and Lidz, B.H., 1977, Topographic control and accumulation rate of some Holocene coral reefs, south Florida and Dry Tortugas: Proceedings, 3rd International Coral Reef Symposium, v. 2, Geology, p. 1-7.

Shinn, E.A., Lidz, B.H., and Holmes, C.W., 1990, High-energy carbonate-sand accumulation, The Quicksands, southwest Florida Keys: Journal of Sedimentary Petrology, v. 60, no. 6, p. 952-967.

Shinn, E.A., Lidz, B.H., Kindinger, J.L., Hudson, J.H., and Halley, R.B., 1989, Reefs of Florida and the Dry Tortugas: A guide to the modern carbonate environments of the Florida Keys and the Dry Tortugas: 28th International Geological Congress, American Geophysical Union, Field Trip Guidebook T176, 53 pp.

Turney, W.J., and Perkins, R.F., 1972, Molluscan distribution in Florida Bay: Sedimenta III, Comparative Sedimentology Laboratory, Division of Marine Geology and Geophysics, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Fla., 37 pp.

U.S. National Museum Proceedings, 1882, Smithsonian Institution, Government Printing Office, Washington, D.C., vol. IV, 1881, p. 74-205.

Vaughan, T.W., 1910, A contribution to the geologic history of the Floridian Plateau: Carnegie Institution of Washington Publication, Papers of the Department of Marine Biology, v. 4, p. 99-185.

Vaughan, T.W., 1914a, Sketch of the geologic history of the Florida coral reef tract and comparisons with other coral reef areas: Journal of the Washington Academy of Sciences, v. IV, no. 2, p. 26-34.

Vaughan, T.W., 1914b, Building of the Marquesas and Tortugas atolls and a sketch of the geologic history of the Florida reef tract: Carnegie Institution of Washington Publication 182, Papers of the Department of Marine Biology, v. 5, p. 55-67.

Vaughan, T.W., 1915, Growth-rate of the Floridian and Bahamian shoal-water corals: Carnegie Institution of Washington Yearbook, no. 13, p. 221-231.

Vaughan, T.W., 1916, The temperature of the Florida coral reef tract: Carnegie Institution of Washington Publication 213, p. 321-339.

Section IV

Appendix

Dry Tortugas Milleporina and Scleractinia species

Phylum Cnidaria

Class Hydrozoa, Owen 1843
- Order Milleporina Hickson 1901
  - Family Milleporidae Fleming 1828
    - *Millepora alcicornis* Linnè 1758
    - *Millepora complanata* Lamarck 1816

Class Anthozoa Ehrenberg 1834
- Order Scleractinia Bourne 1900
  - Family Astrocoeniidae Koby 1890
    - *Stephanocenia intersepta* (Lamarck, 1816)
  - Family Pocilloporidae Gray 1842
    - *Madracis decactis* (Lyman 1859)
    - *Madracis pharensis* (Heller, 1868)
    - *Madracis mirabilis* (*sensu* Wells 1973)
    - *Madracis formosa* Wells 1973
  - Family Acroporidae Verrill 1902
    - *Acropora cervicornis* (Lamarck 1816)
    - *Acropora palmata* (Lamarck 1816)
    - *Acropora prolifera* (Lamarck 1816)
  - Family Agariciidae Gray 1847
    - *Agaricia agaricites* (Linnè 1758)
      - Forma *agaricites* (Linnè 1758)
      - Forma *purpurea* (LeSeuer 1821)
      - Forma *humilis* Verrill 1901
      - Forma *carinata* Wells 1973
    - *Agaricia lamarcki* (Milne Edwards and Haime 1851)
    - *Agaricia fragilis* (Dana 1846)
    - *Leptoseris cucullata* (Ellis and Solander 1786)
  - Family Siderastreidae Vaughan and Wells 1943
    - *Siderastrea radians* (Pallas, 1766)
    - *Siderastrea siderea* (Ellis and Solander 1786)
  - Family Poritidae Gray 1842
    - *Porites astreoides* Lamarck 1816
    - *Porites branneri* Rathbun 1887
    - *Porites porites* (Pallas 1766)
      - Forma *porites* (Pallas 1766)
      - Forma *clavaria* Lamarck 1816
      - Forma *furcata* Lamarck 1816
      - Forma *divaricata* LeSueur 1821

Family Faviidae Gregory 1900
- *Favia fragum* (Esper 1795)
- *Favia gravida* Verrill 1868
- *Diploria labyrinthiformis* (Linnè 1758)
- *Diploria clivosa* (Ellis and Solander 1786)
- *Diploria strigosa* (Dana 1846)
- *Manicina areolata* (Linnè 1758)
  - Forma *areolata* (Linnè 1758)
  - Forma *mayori* Wells 1936
- *Colpophyllia natans* (Houttuyn 1772)
- *Cladocora arbuscula* (LeSueur, 1821)
- *Montastraea annularis* (Ellis and Solander 1786)
  - Forma *annularis* (Ellis and Solander 1786)
  - Forma *faveolata* (Ellis and Solander 1786)
  - Forma *franksi* (Gregory 1895)
- *Montastraea cavernosa* (Linnè 1767)
- *Solenastrea hyades* (Dana 1846)
- *Solenastrea bournoni* (Milne Edwards and Haime 1849)

Family Rhizangiidae D'Orbigny 1851
- *Astrangia soliteria* (LeSueur 1817)
- *Astrangia poculata* (Milne Edwards and Haime 1848)
- *Phyllangia americana* (Milne Edwards 1850)

Family Oculinidae Gray 1847
- *Oculina diffusa* Lamarck 1816
- *Oculina robusta* Pourtales 1871

Family Meandrinidae
- *Meandrina meandrites* (Linnè 1758)
  - Forma *meandrites* (Linnè 1758)
  - Forma *danai* Milne Edwards and Haime 1848
- *Dichocoenia stokesi* Milne Edwards and Haime 1848
- *Dendrogyra cylindrus* Ehrenberg 1834

Family Mussidae Ortmann 1890
- *Mussa angulosa* (Pallas 1766)
- *Scolymia lacera* (Pallas 1766)
- *Scolymia cubensis* (Milne Edwards and Haime 1849)
- *Isophyllia sinuosa* (Ellis and Solander 1786)
- *Isophyllastraea rigida* (Dana 1846)
- *Mycetophyllia lamarckiana* (Milne Edwards and Haime 1849)
- *Mycetophyllia danaana* (Milne Edwards and Haime 1849)
- *Mycetophyllia ferox* Wells 1973
- *Mycetophyllia aliciae* Wells 1973

Family Caryophylliidae
- *Eusmilia fastigiata* (Pallas 1766)

Tributes to the Accomplishments at the Tortugas Laboratory

Tortugas Marine Laboratory: Threshold to Modern Sponge Biology

Klaus Rützler, Research Biologist, Department of Invertebrate Zoology, and Director, Caribbean Coral Reef Ecostystems Program, Smithsonian Institution

Animal or plant species can only be fully understood after they have been observed live in their environment, perhaps even manipulated in some experimental way. Sponges are no exception, but until the dawn of the 20th Century, poriferologists were museum people who processed the dry or alcohol-preserved material sent by beach combers and visitors to foreign shores, or brought home by sea-faring expeditions, for instance the *Blake*, *Challenger*, *Albatross*, *Hirundelle*, *Valdivia*, *Endevour*, *German South Polar*, *Percy Sladen Trust*, and many more. The early marine stations were all located in Europe, in harbors of cities or towns such as Naples, Rovinj, Monaco, Roscoff, and Plymouth.

Establishing the Tortugas Marine Laboratory on Loggerhead Key, Florida, was revolutionary in many ways. The laboratory was the first marine field station in the tropical Americas and was located on a small island that itself was part of the coral reef ecosystem to be studied. The facilities were simple but invited ingenious improvisation for experimental study of organisms that were readily available from nearby habitats. And, in addition to the conventional dredges and sponge hooks used to obtain sessile benthic organisms, a "diving apparatus" was available. This apparatus, a diving helmet made popular in the writings of William Beebe, was first used by the only sponge scientist to work at the laboratory, Max Walker de Laubenfels, who wrote after a walk on the bottom of the reef that "comparisons to a 'fairyland' are appropriate."

During the summers of 1927 and 1928, de Laubenfels conducted a cell-physiology study involving the common Caribbean sponge *Iotrochota birotulata*, and a second species that he described as new, *Haliclona longleyi*, named after W.H. Longley, the Executive Officer of the Tortugas Marine Laboratory. To demonstrate the effect of different temperatures on cell aggregation and growth (and improvisational skills in a place where electricity was not an around-the-clock convenience), he used a "double wooden tunnel... with wood wool or excelsior between inner and outer layers for insulation. Ice was placed at one end, the other left open to the tropical air."

Sponges were also the subject of interest of another worker in the Tortugas at the time, Arthur S. Pearse, who spent the summer of 1931 examining the rich fauna of endobionts occupying the vast canal system of five species of common reef sponges (identified by de Laubenfels), including the common and huge *Spheciospongia vesparium* (appropriately, its common name is loggerhead sponge). Pearse found and identified between about 6,000 and 17,000 specimens of polychaete worms, crustaceans, brittle stars, and fishes in sponges ranging in volume from 50 to 185 liters.

De Laubenfels returned to the Tortugas Marine Laboratory "at the edge of the Gulf Stream [which] offers most favorable conditions for biological work, especially in regard to sponges" during June–August, 1932. He and laboratory staff collected at many sites, shallow and deep, primarily E and SE of Loggerhead Key (4–20 m, 70–80 m), Bird Key and Bush Key reefs (0–15 m), Garden Key (2–25 m), including the Fort Jefferson moat (0–1 m), White Shoals (15–20 m), and partway to Cuba (105 m, 1047 m). In the resulting monograph (published in 1936), de Laubenfels not only described the 77 species he found but he went much farther by providing revised diagnoses of all known genera and families of sponges, a truly pioneering work. The *Sponge Fauna of the Dry Tortugas* also stands out for live observations of color, structure, consistency, and smell and comments on habitats and environmental conditions, such as substratum, light exposure, temperature, water movement, sedimentation, and biological associates. The voucher material of this study is deposited in the sponge collection of the Department of Invertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, D.C. (formerly U.S. National Museum, USNM).

References

Laubenfels, M.W. de, 1932, Physiology and morphology of Porifera exemplified by *Iotrochota birotulata* Higgin: Papers from Tortugas Laboratory 28, Carnegie Institution of Washington Publication 435, p. 1–66.

Laubenfels, M.W. de, 1936, A discussion of the sponge fauna of the Dry Tortugas in particular and the West Indies in general, with material for a revision of the families and orders of the Porifera: Papers from Tortugas Laboratory 30, Carnegie Institution of Washington Publication 467, p. 1–225.

Pearse, A.S., 1934, Inhabitants of certain sponges at Dry Tortugas: Papers from Tortugas Laboratory 28, Carnegie Institution of Washington Publication 435, p. 117–124.

Researchers at the Carnegie Laboratory for Marine Biology in the Tortugas Laid the Firm Foundations (1905-1937) for 20th-Century Reef Science

Peter W. Glynn, Professor of Ecology
Rosenstiel School of Marine and Atmospheric Science, University of Miami

Besides being the first permanently based tropical marine laboratory in the Western Hemisphere, the Tortugas Marine Laboratory hosted the research activities of the most distinguished national and international coral reef scientists of the first half of the 20th Century. Alfred G. Mayor, the founding Director of the laboratory, was the first worker to demonstrate that reef-building corals live precariously close to their upper temperature-tolerance limits. He also found that the fastest growing corals were the most susceptible to elevated temperature stress. Coral growth-rate studies, the early life history of corals, their tolerance to various physical stressors, and nutritional needs were also investigated at the Tortugas Laboratory by T. Wayland Vaughan and his student J.W. Wells. Vaughan later became the Director of the Scripps Institution of Oceanography and J.W. Wells the doyen of American coral reef science. The saturation state of CO_2 in Tortugas reef waters, a critical control of the precipitation of coral limestone skeletons, was studied by R.C. Wells. All of these early studies were prescient vis-à-vis present-day concerns with global warming, coral reef bleaching, and the degradation of coral reefs on a global scale.

Mindful of the power of the comparative approach in science, Mayor extended his studies of Tortugas reef coral ecology to the wider Caribbean region (Bahamas, Jamaica, Puerto Rico, and Trinidad-Tobago) and to the far western Pacific (Torres Strait, Fiji, and American Samoa). Several scientists from other countries also visited and conducted comparative studies at the Tortugas Laboratory. Notable among these workers were H. Boschma, the world's authority on fire corals, and Sir MauriceYonge, the leader of the Great Barrier Reef Expedition. Inspired by his work at Tortugas, C.H. Edmondson continued with and pioneered the first ecological and physiological studies of corals in Hawaii. R.A. Daly, another celebrated geologist who challenged the ideas of C. Darwin and J. Dana on reef development and growth, also worked in the Dry Tortugas. We present-day coral reef researchers and students stand on the shoulders of these giants of the Tortugas Laboratory.

References

Colin, P.L., 1980, A brief history of the Tortugas Marine Laboratory and the Department of Marine Biology, Carnegie Institution of Washington, in Sears, M., and Merriman, D., eds., Oceanography: The Past: Springer-Verlag, p. 138-147.

Edmondson, C.H., 1928, The ecology of an Hawaiian coral reef: Bulletin of the B. P. Bishop Museum, no. 45, 64 pp.

Mayer, A.G., 1914, Effects of temperature on tropical marine animals: Carnegie Institution of Washington Publication, no. 183, 24 pp.

Mayer, A.G., 1918, Ecology of the Murray Island coral reef: Carnegie Institution of Washington Publication, no. 213, p. 1-48.

Mayor, A.G., 1924, Structure and ecology of Samoan reefs: Carnegie Institution of Washington Publication, no. 340, p. 1-25.

Schmidt, T.W., and Pikula, L., 1997, Scientific studies on Dry Tortugas National Park: An annotated bibliography: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and U.S. Department of the Interior, National Park Service, 108 pp.

Vaughan, T.W., 1916, Results of investigations of the ecology of the Floridian and Bahaman shoal-water corals: Proceedings of the National Academy of Science, v. 2, p. 95-100.

Wells, R.C., 1922, Carbon-dioxide content of sea water at Tortugas: Papers of the Tortugas Laboratory, v. 18, p. 87-93.

Study of Living Algae in the Tortugas Produced the "Bible" for Identifying Those of the Tropical Atlantic

Diane S. Littler, Senior Scientist, Harbor Branch Oceanographic Institution

Mark M. Littler, Senior Scientist, NMNH, Smithsonian Institution

To us, it seems like the Tortugas Laboratory, maintained for many years by the Carnegie Institution of Washington, is still in existence even though the actual facility has been gone for many years. We refer to the algal literature and specimens that originated at the facility almost every day. Many of the latter are housed and available for study in the algal herbarium of the National Museum of Natural History, Smithsonian Institution. The "bible" for marine algal identification for the Caribbean, William Randolph Taylor's *Marine Algae of the Eastern Tropical and Subtropical Coasts of the Americas*, published in 1960, was initiated and inspired by the work that he did at the station between 1924 and 26. He writes in the first line of the preface, "This work is the direct, if slowly matured, result of the three stimulating summer periods I spent at the former Dry Tortugas Laboratory of the Carnegie Institution of Washington (1924 and 26)." He states the conditions were Spartan but ideal for field and simple laboratory studies.

Algal taxonomy benefits tremendously from studying living material, as opposed to dried, pressed (mostly damaged) specimens that most herbarium-based researchers are forced to use, especially in the early part of the 1900s. The opportunity to work at a field station such as the Carnegie Lab in the Dry Tortugas gave Taylor not only the inspiration of seeing the plants alive but also added enormously to his ability to describe accurately the species color, texture, and other features that are critical for identification and are often missed or impossible to obtain from pressed specimens. Taylor's initial intent was to prepare a checklist of the algae at the Dry Tortugas to aid other workers at the lab who were working in other fields; however, he found such a rich flora in the area that the checklist soon developed into *The Marine Algae of Florida with Special Reference to the Dry Tortugas*, published by the Carnegie Institution of Washington in 1928, which he eventually expanded upon and developed into *Marine Algae of the Eastern Tropical and Subtropical Coasts of the Americas*, to this day, a critical resource for anyone working with seaweeds in the Western Atlantic.

References

Taylor, W.R, 1928, The marine algae of Florida with special reference to the Dry Tortugas: Publications of the Carnegie Institution of Washington, no. 379, [v] + 220 pp.

Taylor, W.R., 1960, Marine algae of the eastern tropical and subtropical coasts of the Americas: University of Michigan Press, Ann Arbor, xi + [iii] + 870 pp.

Systematics and Behavior of Tropical Atlantic Marine Fishes were Pioneered by William H. Longley at the Tortugas Laboratory

C. Richard Robins, Curator Emeritus and Research Associate, University of Kansas Natural History Museum and Biodiversity Research Center

The term "pioneer study" is often broadly applied, but I can think of no work on tropical fishes more deserving of that accolade than the work by William H. Longley on fishes of the Tortugas region. Considering the abysmal lack of published information on the tropical Atlantic fish fauna in the 1930s and the unavailability of collections, Longley's work was truly remarkable. He combined underwater observations of behavior and ecology, made with the use of diving helmets with external air supply, with notes on systematics and relationships, and he collected and preserved specimens on which his observations were based. To my knowledge, he was the first to make direct underwater observations on the fishes of the coral reef community. He died before he could complete his book, but his notes and collections were sent to Samuel F. Hildebrand. Hildebrand sorted Longley's notes by species, identified those species, and commented on systematic problems, but the field observations, some of which unfortunately could not be assigned properly, are all by Longley. The resultant book by Longley and Hildebrand, published in 1941, was indispensable to me as I started my studies on marine fishes at the University of Miami in 1956 and to Dr. James E. Böhlke as he began his studies on Bahamian fishes in 1955. Although there were published reports on isolated collections of fishes from Bermuda, the Bahamas by Beebe and Tee-Van, Breder, Fowler, and Mowbray, Longley's studies provided the real starting point for correlating the observations we were making using face mask, snorkel, and scuba gear. Longley's studies in the Tortugas were thus of paramount importance.

References

Beebe, W., and Tee-Van, J., 1928, The fishes of Port-au-Prince Bay, Haiti, with a summary of the known species of marine fish of the island of Haiti and Santo Domingo: Zoologica, New York, v. 10, no. 1, p. iii-xi, 1-279, 268 figures, 1 map.

Beebe, W., and Tee-Van, J., 1933, Field Book of the Shore Fishes of Bermuda: New York, G.P. Putnam's Sons, i-xiv, p. 1-337, many figures.

Breder, C.M., Jr., 1948, Field Book of Marine Fishes of the Atlantic Coast: New York, G.P. Putnam's Sons, i-xxxvii, p. 1- 332.

Fowler, H.W., 1952, Memorias de la Sociedad Cubana de Historia Natural, v. 21, no.1, p. 83-115, pls. 20-26.

Mayor's Work on Medusae: Still the best!

Allen G. Collins, National Systematics Laboratory of NOAA Fisheries Service, and National Museum of Natural History, Smithsonian Institution

Lisa-ann Gershwin, SLSQ Marine Stinger Advisor, School of Marine Biology and Aquaculture, James Cook University, Townsville, Queensland, Australia

Perhaps only a fellow medusaphile would really understand, but Alfred Goldsborough Mayor had an extreme fondness for jellyfishes. Indeed, in *Medusae of the World* (Mayer, 1910), he described these "creatures of the sea" as possessing a "rare grace of form and delicate beauty of color" that one could not help but appreciate. These words are found in the introduction of his great book, but the sentiment comes through in the lucid prose and exquisite figures throughout. Though Mayor described his text as dry, it is anything but. Indeed, the day during graduate school that one of us (LG) gave the other (AC) a copy of his book was a momentous event for both, the former welcoming the latter through this right of passage. The modest but confident tone of the introduction combined with the richness but accessibility of the content opened up the possibility of joining in on the study of these wondrous creatures. In addition to taxonomic descriptions, Mayor presented information on every aspect of natural history as well as many opinions on the intriguing evolutionary history of medusozoans. They simply do not write them like they used to!

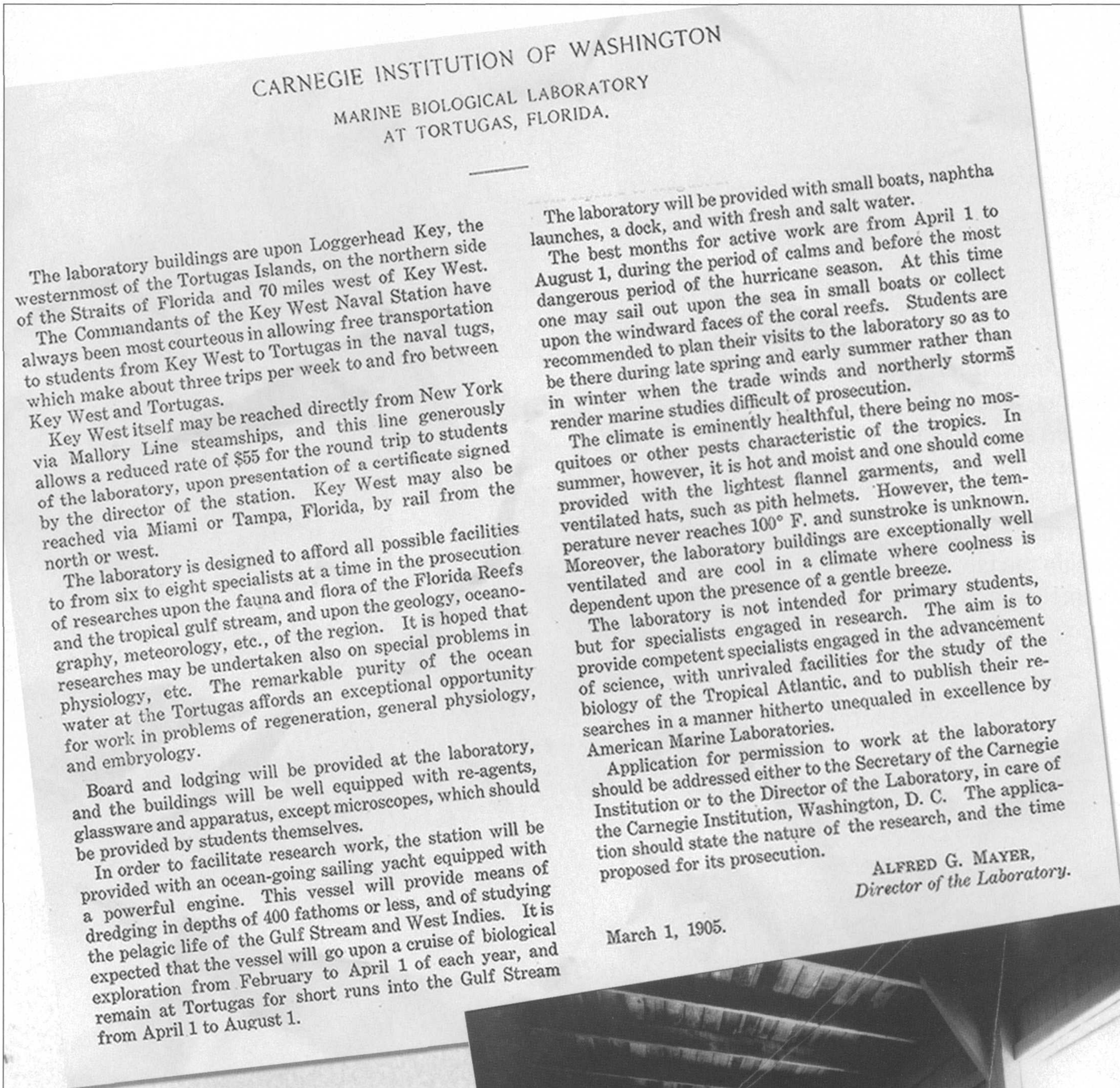
In fact, they simply do not do systematics like they used to. Even though species recognition remains a crucial task to biodiversity and conservation studies (Balakrishnan, 2005), species-level systematics is woefully under funded and consequently under pursued. One gets the impression that Mayor's sentiment that "each working naturalist owes it as a duty to science to produce some general systematic work" was more commonly held a century ago. Because of his aptitude, Mayor was handsomely supported in his work by Alexander Agassiz, with whom he traveled extensively. In fact, his *Medusae of the World* was a culmination of work begun in 1892 as a collaborative project at the direction of Agassiz. Although Agassiz generously supported Mayor's pursuits, he became too busy to participate in the work and unfortunately never lived to see publication of the treatise.

Mayor's book was a landmark publication because it was the first synthetic treatment of medusae in English. Even today, it remains an essential desk reference for cnidarian biologists, and Mayor's work continues to be cited often and is highly influential. There have since been many new species discovered, and even a few synopses made, but nothing else comes close to Mayor's comprehensive treatment of all four medusa classes. Mayor modestly wrote in the introduction to *Medusae of the World* that he hoped that "science may be more advanced than hindered through the publication" of his book. We emphatically state, hope fulfilled! Mayor significantly advanced our understanding of these delightfully fascinating animals, and we are grateful.

References

Balakrishnan, R., 2005, Species concepts, species boundaries, and species identification: A view from the tropics: Systematic Biology, v. 54, p. 689-693.

Mayer, A.G., 1910, Medusae of the World: Carnegie Institution of Washington, Washington, D.C., Publlication No. 109, Quarto, 3 vols., 735 pp.



CARNEGIE INSTITUTION OF WASHINGTON

MARINE BIOLOGICAL LABORATORY
AT TORTUGAS, FLORIDA.

The laboratory buildings are upon Loggerhead Key, the westernmost of the Tortugas Islands, on the northern side of the Straits of Florida and 70 miles west of Key West.

The Commandants of the Key West Naval Station have always been most courteous in allowing free transportation to students from Key West to Tortugas in the naval tugs, which make about three trips per week to and fro between Key West and Tortugas.

Key West itself may be reached directly from New York via Mallory Line steamships, and this line generously allows a reduced rate of $55 for the round trip to students of the laboratory, upon presentation of a certificate signed by the director of the station. Key West may also be reached via Miami or Tampa, Florida, by rail from the north or west.

The laboratory is designed to afford all possible facilities to from six to eight specialists at a time in the prosecution of researches upon the fauna and flora of the Florida Reefs and the tropical gulf stream, and upon the geology, oceanography, meteorology, etc., of the region. It is hoped that researches may be undertaken also on special problems in physiology, etc. The remarkable purity of the ocean water at the Tortugas affords an exceptional opportunity for work in problems of regeneration, general physiology, and embryology.

Board and lodging will be provided at the laboratory, and the buildings will be well equipped with re-agents, glassware and apparatus, except microscopes, which should be provided by students themselves.

In order to facilitate research work, the station will be provided with an ocean-going sailing yacht equipped with a powerful engine. This vessel will provide means of dredging in depths of 400 fathoms or less, and of studying the pelagic life of the Gulf Stream and West Indies. It is expected that the vessel will go upon a cruise of biological exploration from February to April 1 of each year, and remain at Tortugas for short runs into the Gulf Stream from April 1 to August 1.

The laboratory will be provided with small boats, naphtha launches, a dock, and with fresh and salt water.

The best months for active work are from April 1 to August 1, during the period of calms and before the most dangerous period of the hurricane season. At this time one may sail out upon the sea in small boats or collect upon the windward faces of the coral reefs. Students are recommended to plan their visits to the laboratory so as to be there during late spring and early summer rather than in winter when the trade winds and northerly storms render marine studies difficult of prosecution.

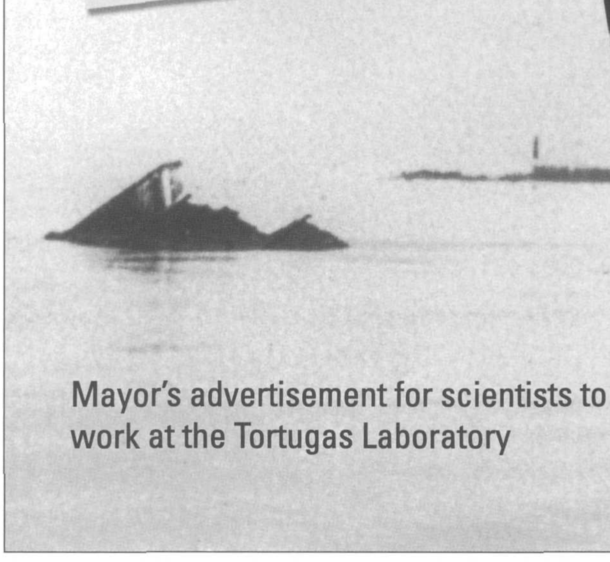
The climate is eminently healthful, there being no mosquitoes or other pests characteristic of the tropics. In summer, however, it is hot and moist and one should come provided with the lightest flannel garments, and well ventilated hats, such as pith helmets. However, the temperature never reaches 100° F. and sunstroke is unknown. Moreover, the laboratory buildings are exceptionally well ventilated and are cool in a climate where coolness is dependent upon the presence of a gentle breeze.

The laboratory is not intended for primary students, but for specialists engaged in research. The aim is to provide competent specialists engaged in the advancement of science, with unrivaled facilities for the study of the biology of the Tropical Atlantic, and to publish their researches in a manner hitherto unequaled in excellence by American Marine Laboratories.

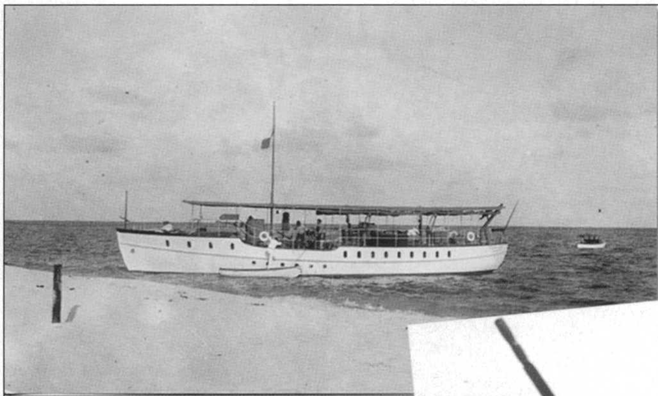
Application for permission to work at the laboratory should be addressed either to the Secretary of the Carnegie Institution or to the Director of the Laboratory, in care of the Carnegie Institution, Washington, D. C. The application should state the nature of the research, and the time proposed for its prosecution.

ALFRED G. MAYER,
Director of the Laboratory.

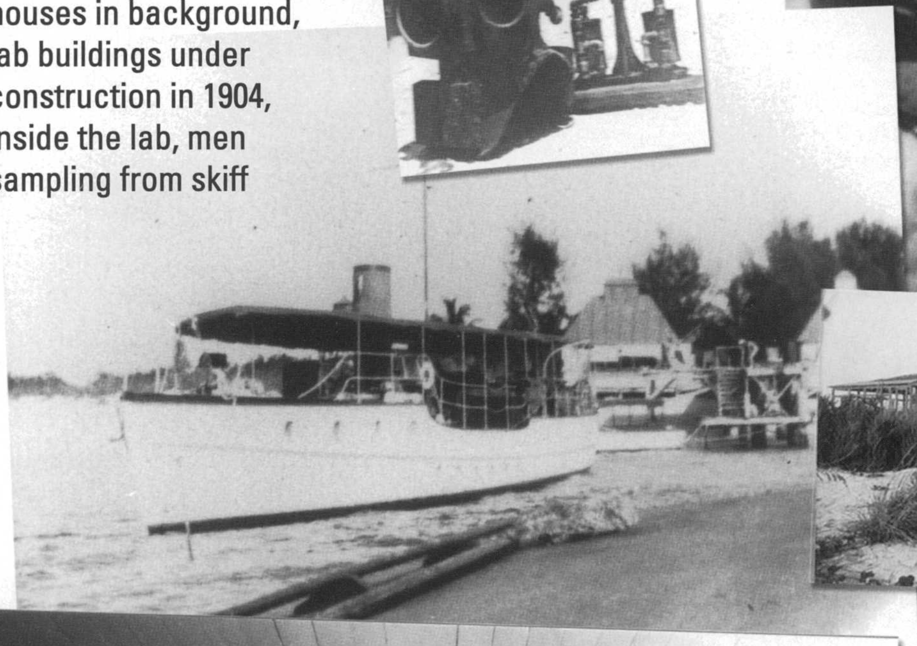
March 1, 1905.

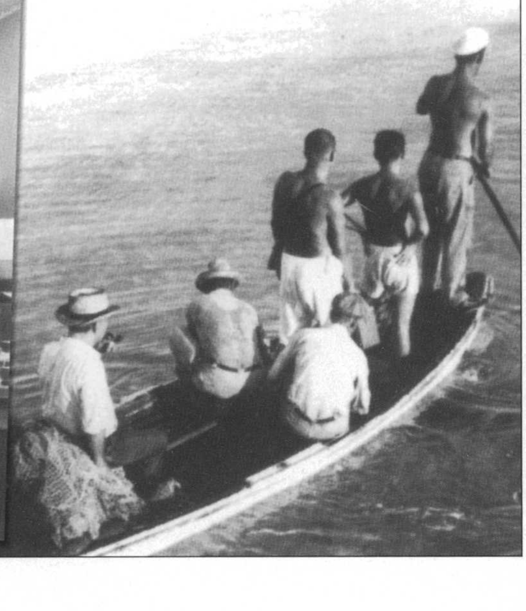


Mayor's advertisement for scientists to work at the Tortugas Laboratory

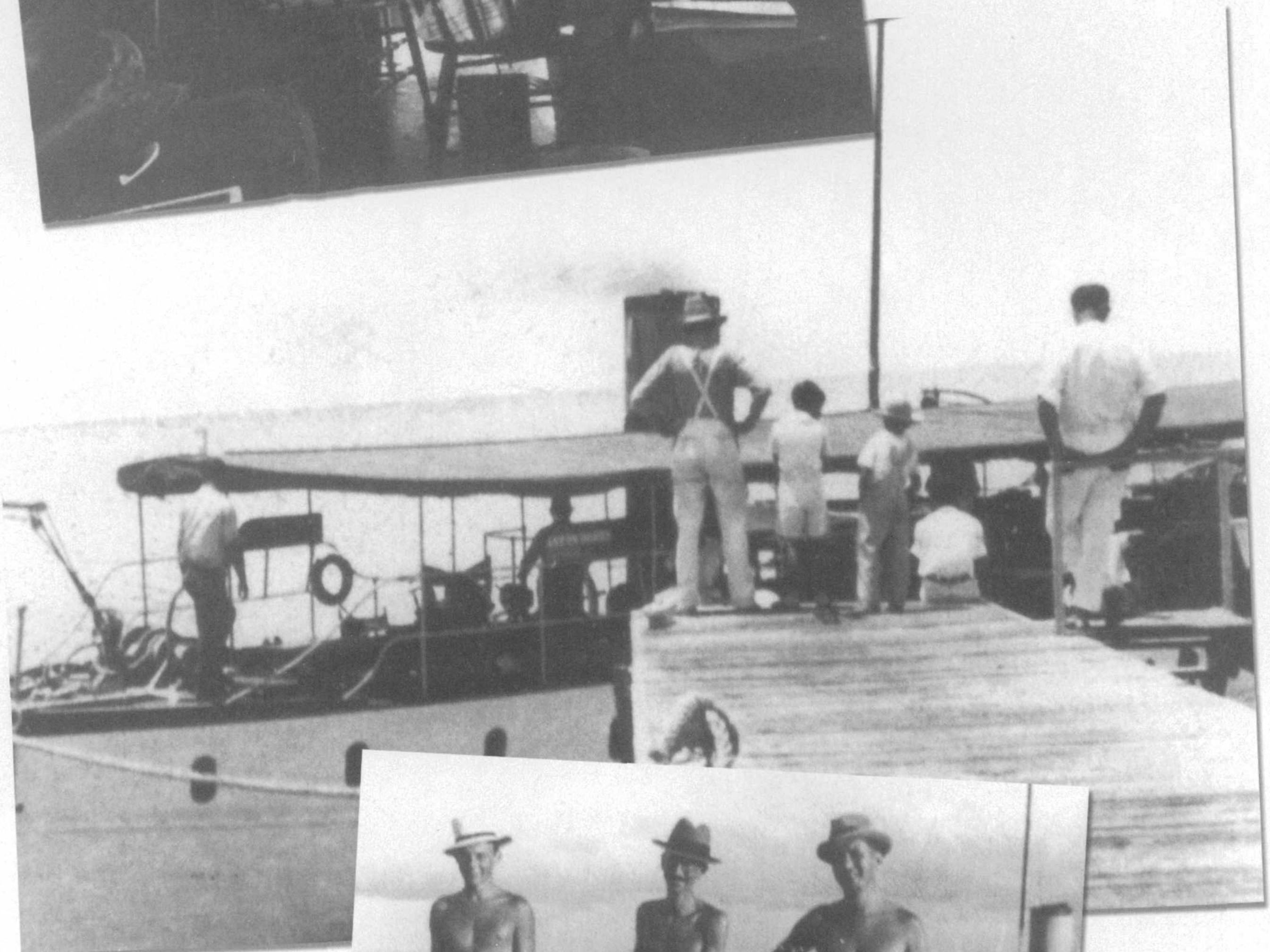


The *Anton Dhorn*, diving helmet, diver, *Anton Dhorn* at dock with dock houses in background, lab buildings under construction in 1904, inside the lab, men sampling from skiff

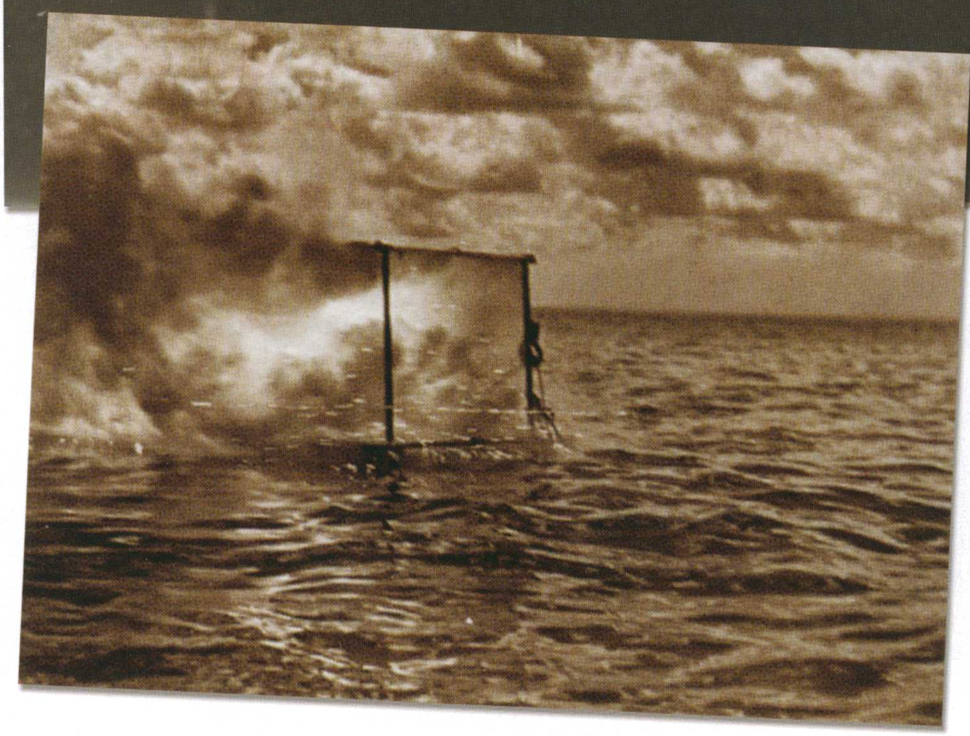




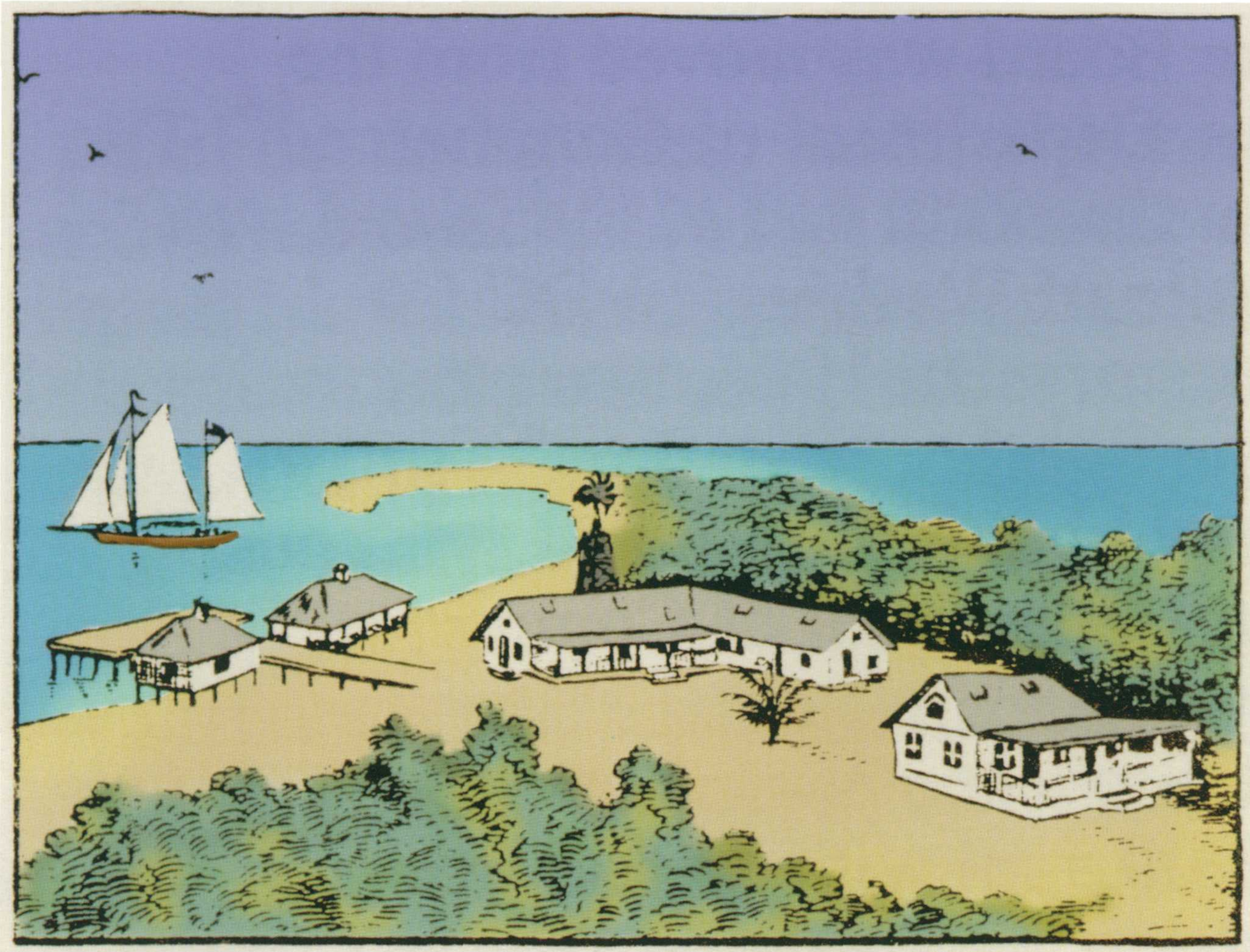
At work aboard the *Anton Dhorn*, docking the *Anton Dhorn* at the Loggerhead Key dock



Three scientists at Loggerhead Key in 1932, man in middle is John W. Wells



Early underwater photo of elkhorn coral and color photo of a hogfish, ignition of magnesium powder (lower photo) was required to provide enough light for color photography, fish in lab aquaria



Artist's sketch of aerial view of the Loggerhead Key Carnegie Research Laboratory as it looked sometime after 1905 (from Hurley, 1994). Compare the two buildings with the photograph in Figure 16. Two houses on either side of the dock can be seen in the background in the photo of the *Anton Dhorn* in the Appendix. Note the windmill that pumped seawater and air to the laboratory. The sailboat off the dock is the *Physalia*, which was decommissioned in 1911.