Chapter 3. Origin and Evolution of Tampa Bay

By Gerold Morrison (AMEC-BCI) and Kimberly K. Yates (U.S. Geological Survey–St. Petersburg, Florida)

TAMPA BAY HAS AN UNUSUAL geologic history when compared to many other estuaries in the eastern U.S. (Brooks and Doyle, 1998; Hine and others, 2009). It lies near the center of the carbonate Florida Platform (fig. 3–1), and is associated with a buried "shelf valley system" (including a paleo-channel feature located beneath the modern Egmont Channel) that formed in the early Miocene, about 20 million years ago (Ma) (Hine, 1997; Donahue and others, 2003; Duncan and others, 2003). Since that time the area has been subject to substantial fluctuations in sea level and alternating periods of sediment deposition and removal. These events have produced a complex distribution of siliciclastic and carbonate-based sediments within the bay, its associated barrier islands, and the inner Florida shelf (Brooks and Doyle, 1998; Brooks and others, 2003; Duncan and others, 2003; Ferguson and Davis, 2003). Sinkholes and other karst features in the underlying carbonate strata, which are common throughout the west-central Florida region, have been important factors underlying the development of both Tampa Bay (Brooks and Doyle, 1998; Donahue and others, 2003) and Charlotte Harbor, a geologically similar estuary located about 100 mi to the south (Hine and others, 2009). In the case of Tampa Bay, the underlying shelf valley system consists of multiple karst controlled subbasins (separated by bedrock highs) that have been filled by sediments, some of which were deposited fluvially (Hine and others, 2009).

The thick carbonate bedrock of the Florida Platform is of mid-Jurassic (about 170 Ma) to Miocene (5 to 22.5 Ma) age, with a karst surface that contains numerous sinkholes, folds, sags and warps. It is covered by a comparatively thin mantle of quartz sand and other sediments. The sand originated in the silicate-rich bedrock of the Appalachian and Piedmont regions of eastern North America, and was transported southward as part of the "siliciclastic invasion" of peninsular Florida that has been occurring since the late Oligocene (more than 22.5 Ma) (Hine and others, 2003; Hine and others, 2009).

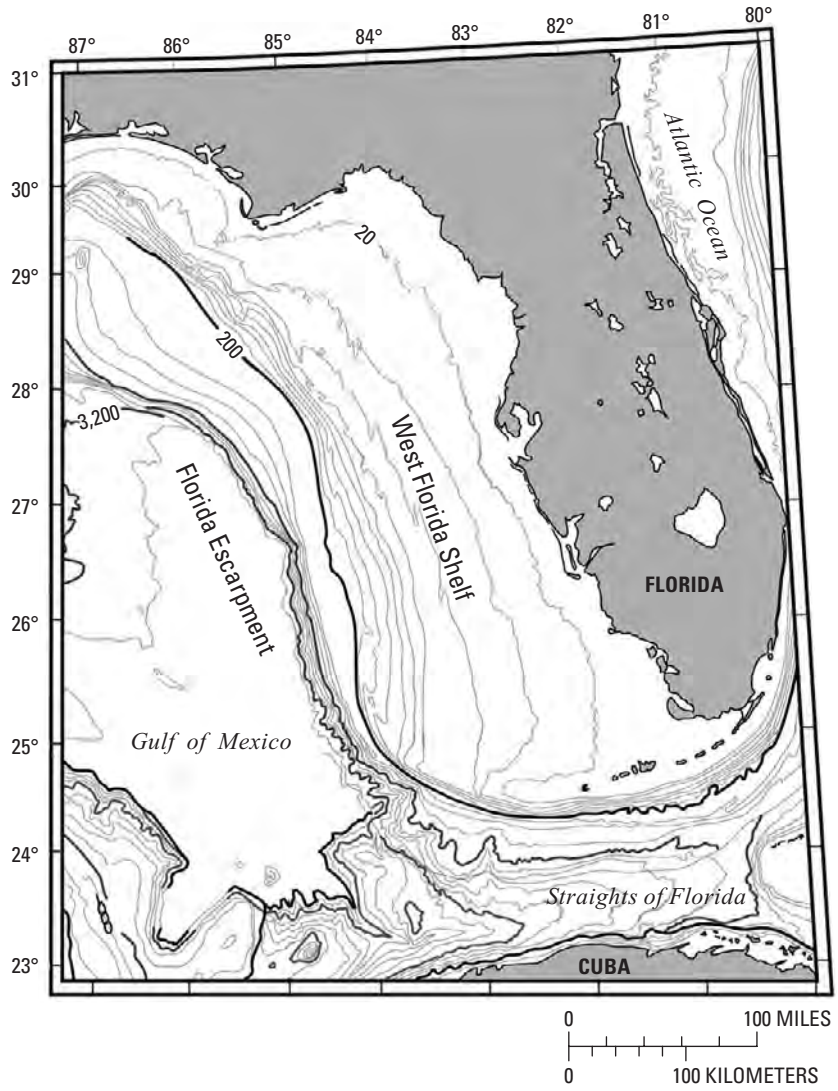


Figure 3–1. The Florida Peninsula and the Florida Platform. From Hine and others (2003) with permission from Elsevier.

More recently, near the end of the last ice age — about 20 thousand years ago (ka) — glaciers held a large percentage of the Earth's water, and global sea level was about 122 m lower than it is today. At that time, the Gulf coast of west-central Florida would have been about 120 mi west of its current position, and the area that is now Tampa Bay was near the center of the Florida Peninsula. The vegetation of the region was savannah-like, supporting a diverse megafauna that included mastodons, giant armadillos, and saber-toothed cats (Allen and Main, 2005). As the ice began to melt during the initial warming that ended the most recent glacial period, about 17.2 ka (Willard and others, 2007), the gulf shoreline migrated inland as sea level rose and the physiography of the Tampa Bay region evolved into the configuration we see today (Donahue and others, 2003; Cronin and others, 2007).

Evidence from seismic data and sediment cores (see box 3–1) indicates that habitat conditions present in the bay area during this period changed from terrestrial to freshwater to estuarine/marine (fig. 3–2) in response to changing sea level and climate (Edgar, 2005; Willard and others, 2007). General changes in shoreline locations and habitat types estimated by Donahue and others (2003) for the past 10,000 to 11,000 years are shown in figure 3–3. About 10 to 11 ka, the shoreline consisted of low barrier islands, with sand ridges forming seaward and a mangrove/marsh mainland lagoon

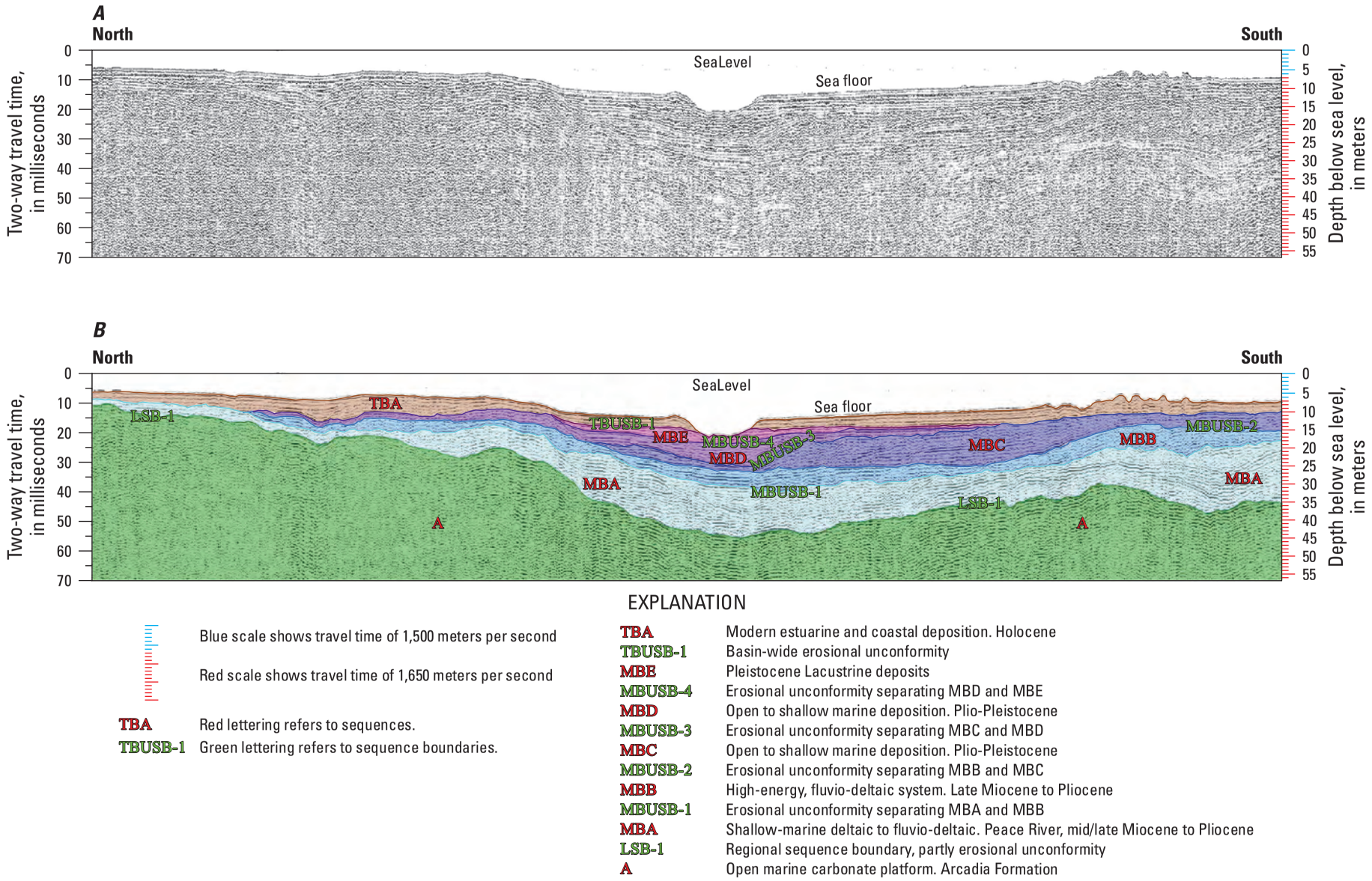


Figure 3–2. Seismic line, showing layers of sediment beneath the bay floor, and locations of the cores that penetrated and recovered sediment from these layers. From Edgar (2005). See box 3–1, fig. 2 for the location of this seismic line.

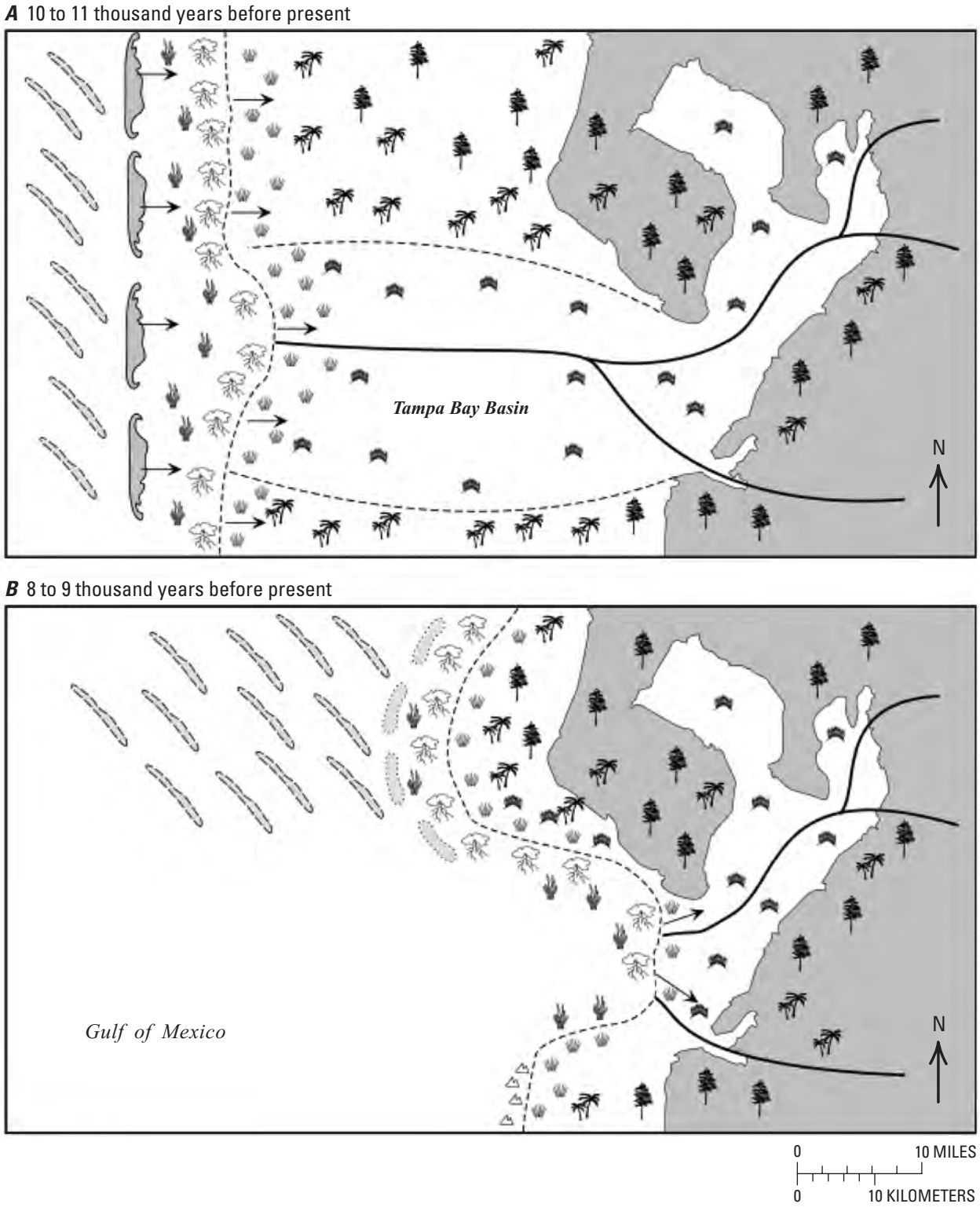
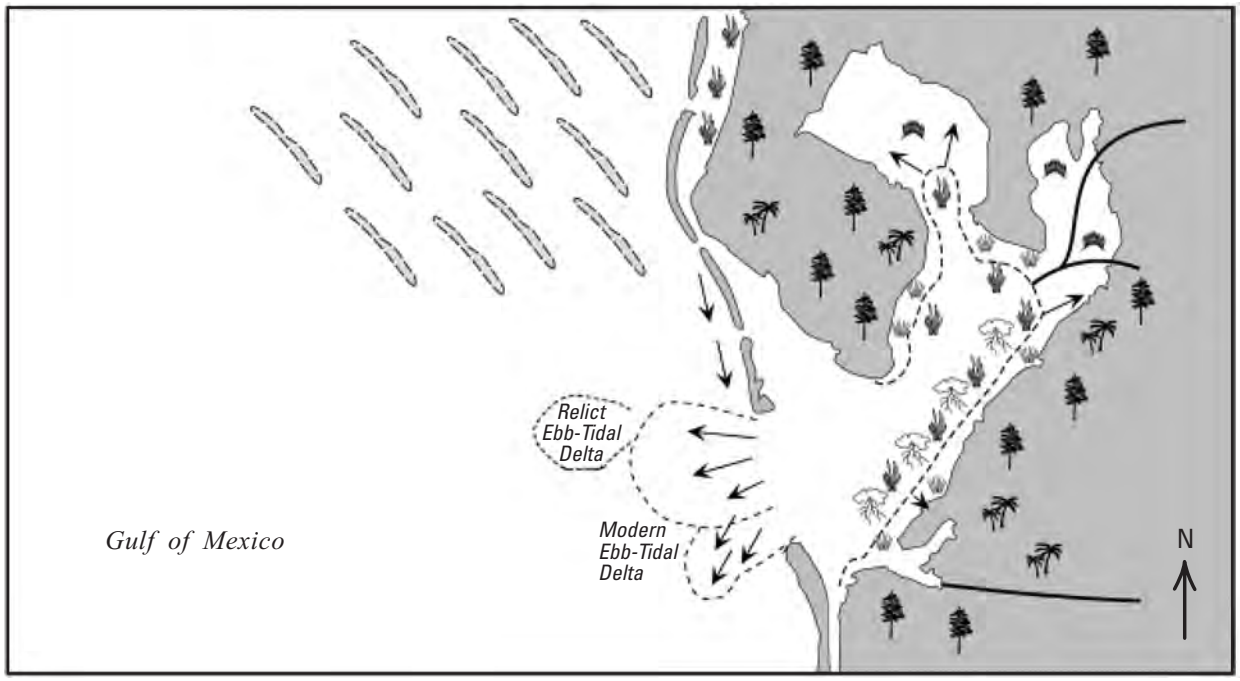


Figure 3–3. *Above and opposite page* The theoretical development of the inner shelf, Tampa Bay estuary, and ebb-tidal delta system from 11,000 to 3,000 years ago. From Donahue and others (2003) with permission from Elsevier.

C 5 to 8 thousand years before present

D 3 thousand years before present



EXPLANATION

Subtidal linear sand ridges

Mangrove / marsh coastline

Seagrasses

Edge of Tampa Bay Basin

Washover dominated barrier island

Rock / marsh coastline

Freshwater wetlands

Upland vegetation

Subtidal swash bars

Modern-day coastline

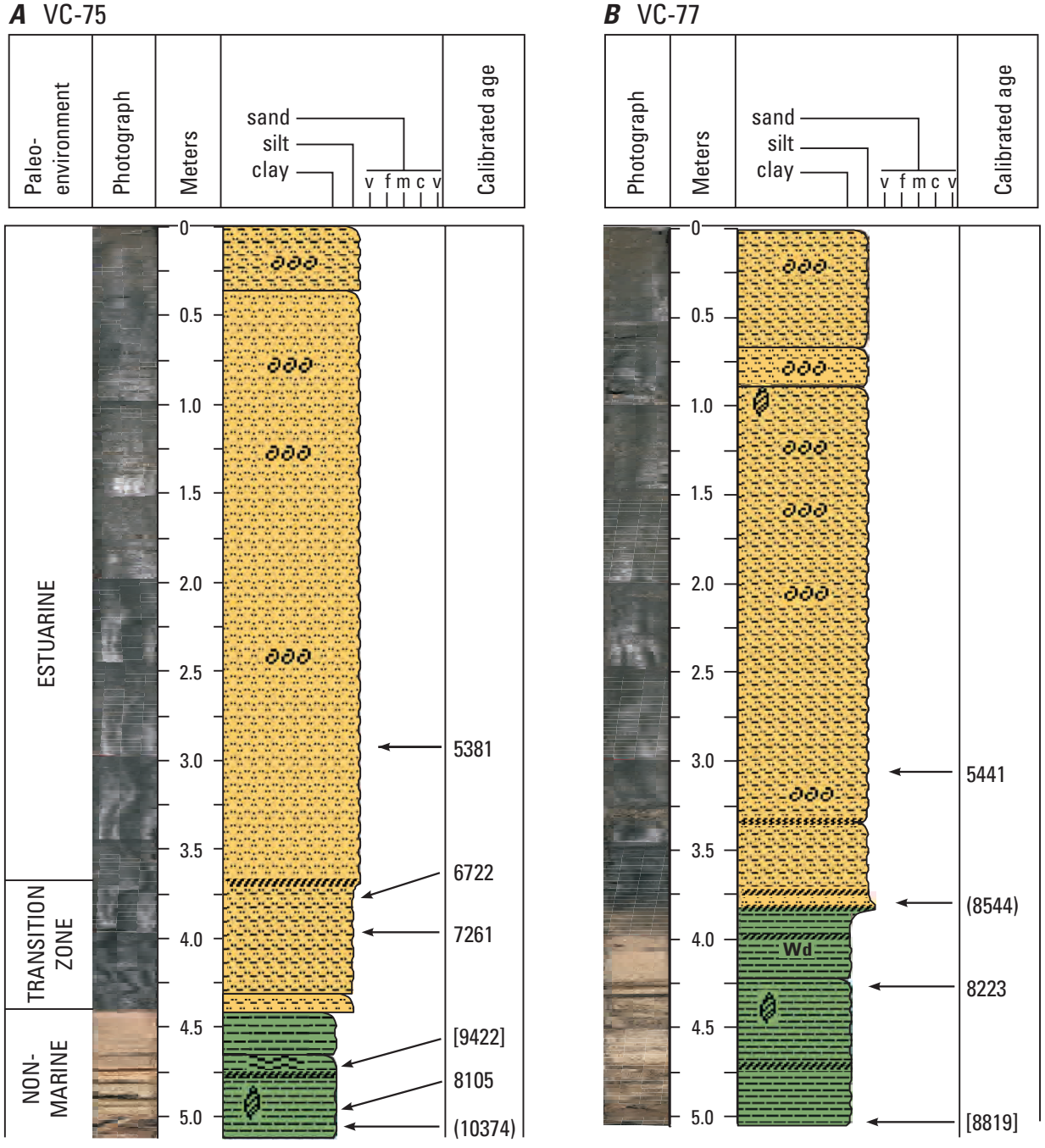
Paleofluvial system

0 10 MILES

0 10 KILOMETERS

shoreline intercepting a slight depression (the Tampa Bay Basin) (fig. 3–3, panel *A*). The area of modern Tampa Bay was a freshwater swamp during this period. By about 8 to 9 ka (panel *B*), the coastline had migrated toward the east with swash bars and low barrier islands forming the shoreline. By 5 to 8 ka (panel *C*), additional eastward shoreline migration had occurred, and by about 3 ka (panel *D*), sea-level rise had slowed and the modern barrier island system was becoming established (Donahue and others, 2003).

More detailed assessments of Holocene sea-level rise, and its relationship to regional and global sea level and polar ice volume, have been performed using stratigraphic and radiocarbon dating information (fig. 3–4) from sediment cores collected at numerous locations within the bay (Cronin



and others, 2007). In figure 3–4, the nonmarine to marine transition (core depth 3.4 to 4.4 m in core VC-75; 3.3 to 3.6 m in core VC-77; and 3.6 to 4.3 m in core VC-78) represents relative sea-level rise in Tampa Bay at about 7 ka. Radiocarbon dates in parentheses are from bulk organic carbon, and those in brackets are from the mollusk Melongea. Some radiocarbon dates may not be reliable due to reworking, transport, or reservoir carbon. (A table of radiocarbon ages can be obtained from *http://gulfsci.usgs.gov/tampabay/data/3_climate_history/index.html*.)

The following sections provide a brief overview of the geologic and physiographic history of the bay basin, of modern climatic and hydrologic conditions, and of manmade alterations of the bay and its watershed.

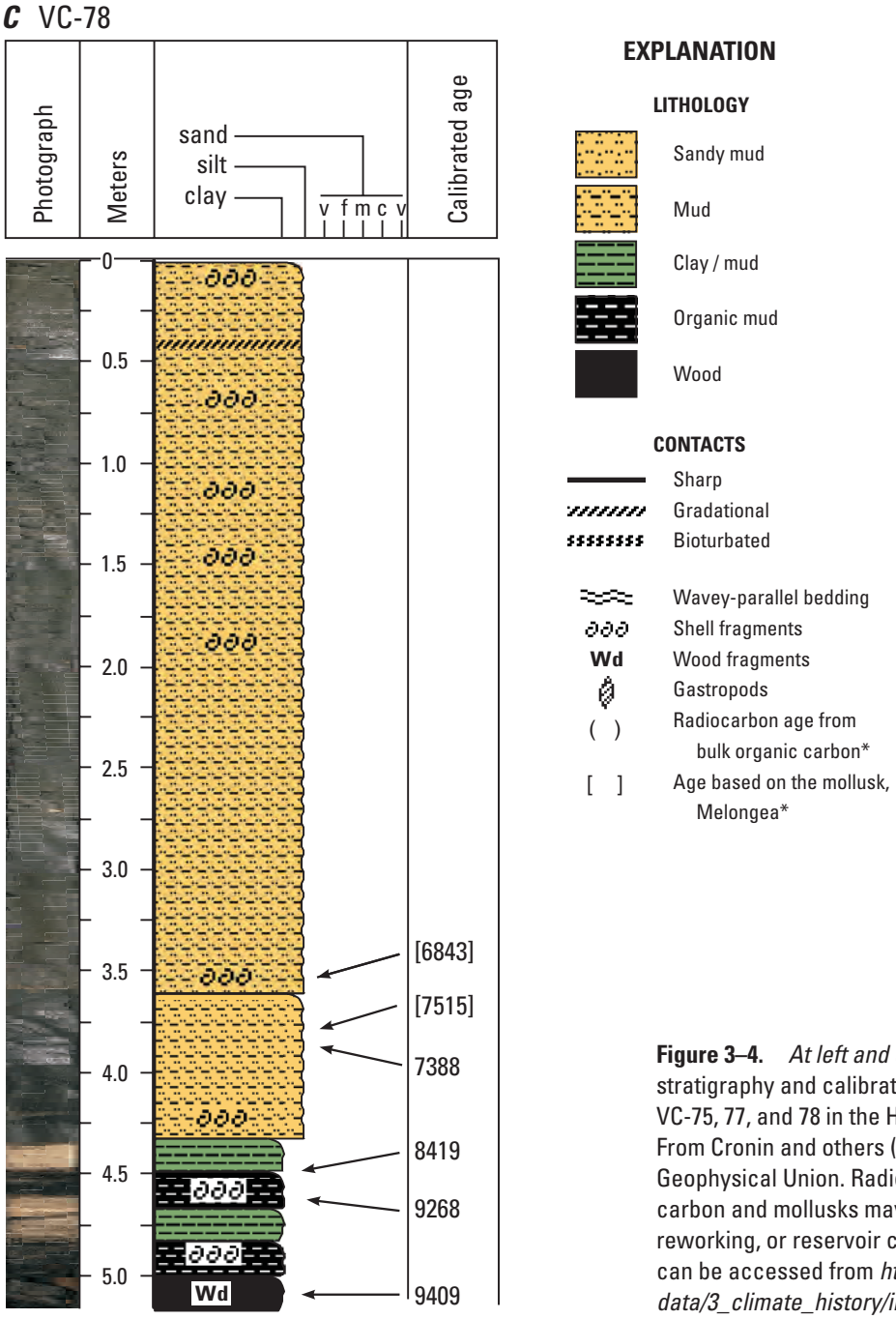


Figure 3–4. *At left and opposite page* Holocene stratigraphy and calibrated radiocarbon dates from cores VC-75, 77, and 78 in the Hillsborough Bay region of Tampa Bay. From Cronin and others (2007) with permission from American Geophysical Union. Radiocarbon ages from bulk organic carbon and mollusks may not be reliable due to transport, reworking, or reservoir carbon. A table of radiocarbon ages can be accessed from *http://gulfsci.usgs.gov/tampabay/data/3_climate_history/index.html*

Box 3–1. Coring to Reconstruct the Past in Tampa Bay

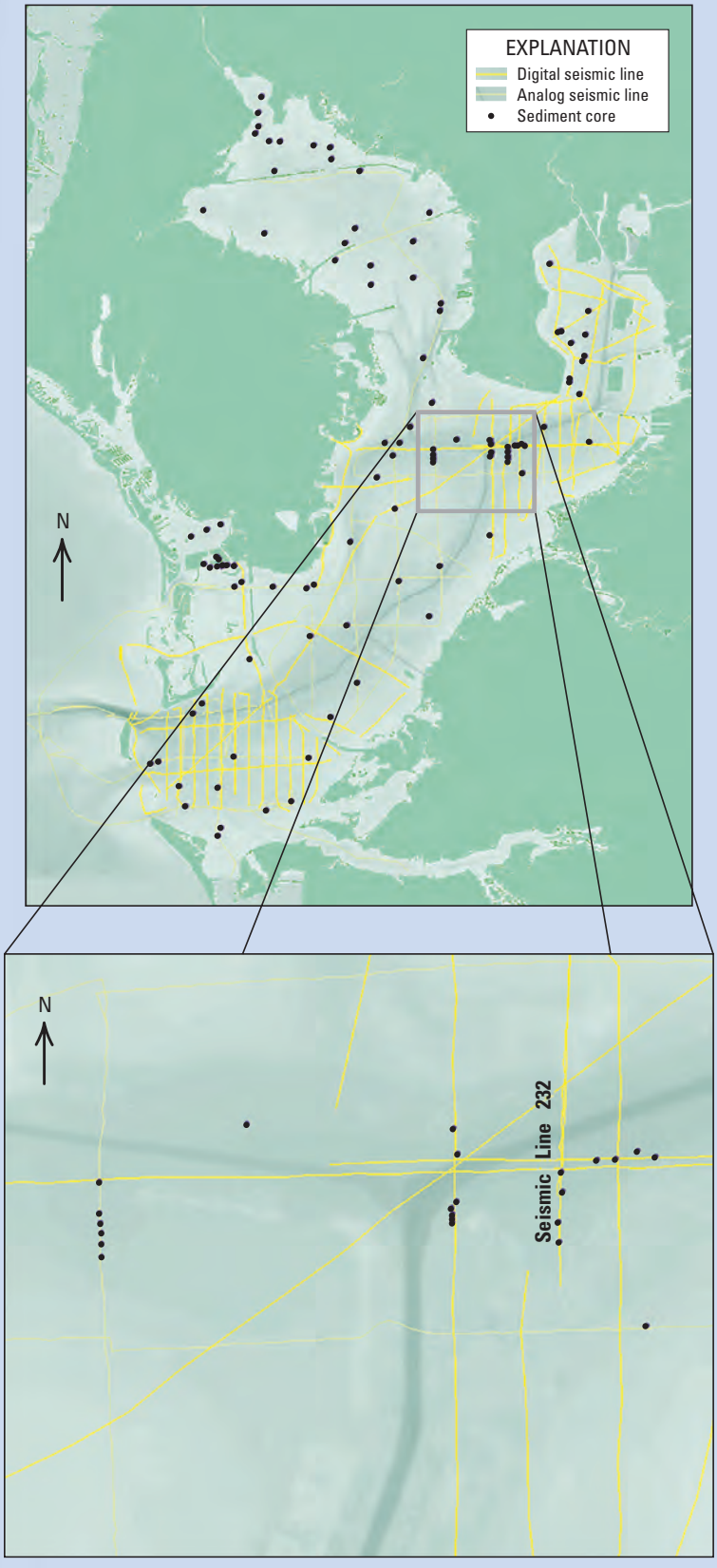
By Kimberly K. Yates and N. Terence Edgar (U.S. Geological Survey–St. Petersburg, Florida), and Thomas M. Cronin, (U.S. Geological Survey–Reston, Virginia)

Knowing the historical and prehistorical environmental conditions for a coastal ecosystem such as Tampa Bay can be very important when determining the effects of climate variability or sea-level change, conducting habitat restoration, or evaluating the health of ecosystems. Sediment cores are a common method for determining prehistorical conditions and the impact of human activity in the bay and its watershed during the historical period.

The USGS, in cooperation with Eckerd College and the University of South Florida (USF), collected over 100 sediment cores throughout Tampa Bay as part of the USGS Tampa Bay Study. The cores were collected from a boat or in the water using either a vibracore or push-core system, and then were brought back into the lab for analysis (box 3–1, fig. 1). The locations of these cores were coordinated with the same locations where seismic reflection profiles were collected. Seismic reflection profiles are also collected using boat-based instrumentation, and provide information on the stratigraphy underlying the sea floor of Tampa Bay. Coordinating core locations with stratigraphic profiles enables extrapolation of data from sediment layers in one core location to sediment layers in cores from other locations within the bay (box 3–1, fig. 2).

Many variables are studied and measured in the sediment, among them grain-size (useful in analysis of turbidity and water clarity), pollen grains (indicators of climate and land use), benthic microfossils (indicators of salinity and water quality), and a variety of geochemical proxies (indicators of salinity, water quality, pollution, etc).

Box 3–1, Figure 1. Vibracore apparatus used to take sediment cores in Tampa Bay. Photo from U.S. Geological Survey.



Box 3–1, Figure 2. Locations of sediment cores (black dots) and seismic track-lines throughout Tampa Bay. Map from U.S. Geological Survey

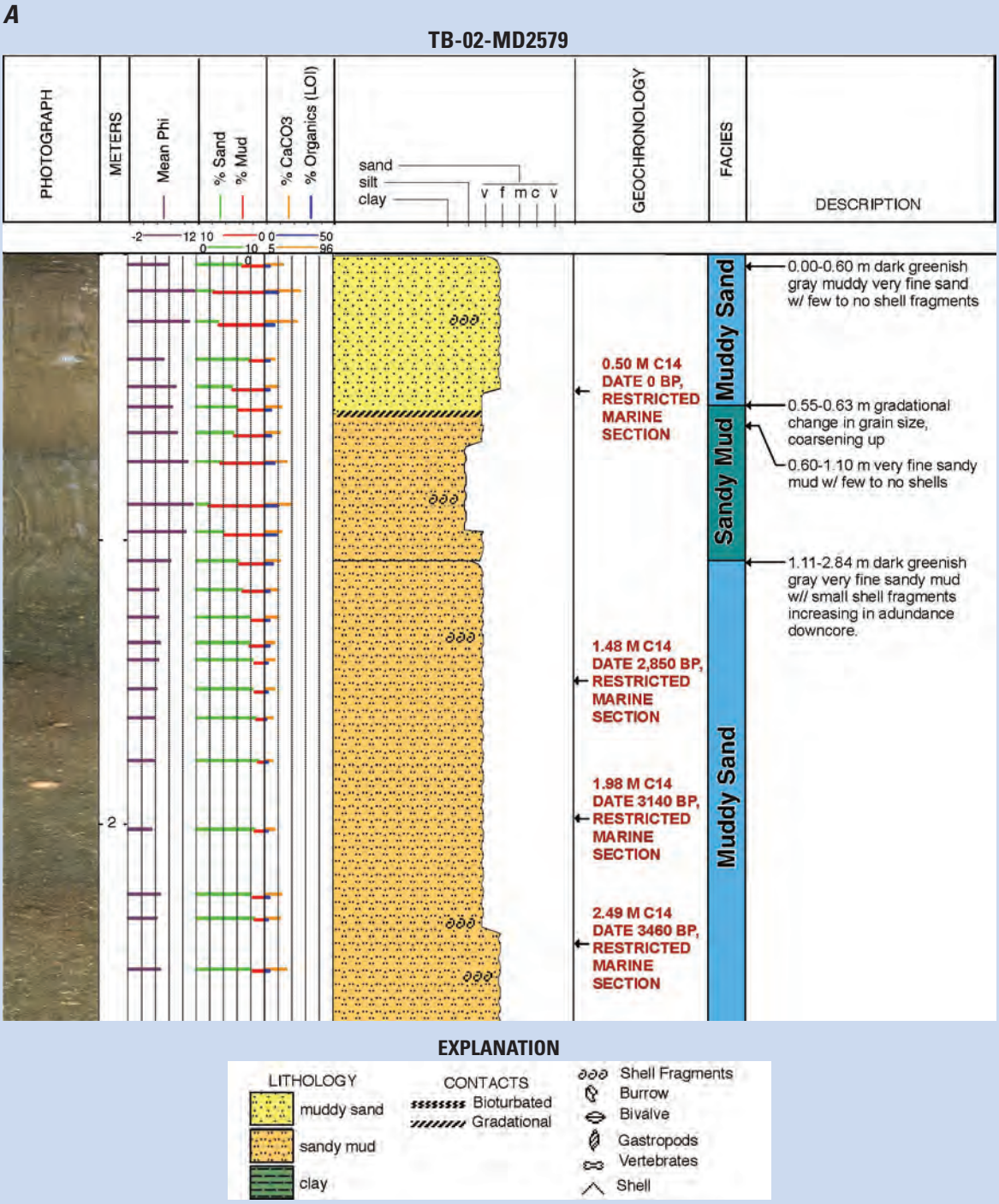
The temporal patterns obtained from these proxies, when interpreted in light of an age model developed from radiocarbon and other dating methods, tell researchers and managers about the environmental health of the bay and how to restore the bay to more pristine conditions.

When France's large research vessel, *Marion Dufresne* (box 3–1, fig. 3), visited Tampa Bay in July of 2002, USGS researchers arranged to have the ship collect three "long" cores in the deepest natural depression, located in Middle Tampa Bay (Edgar, 2002). Seismic data collected by USF researchers indicated that about 16 to 17 m of sediment overlie the deepest recorded seismic reflection in this depression. Water depth in this location was 9 m, allowing the ship only 3 m of clearance between the hull and sea floor, the shallowest water depth from which the *Marion Dufresne* has ever attempted coring operations (box 3–1, fig. 4). The first core recovered 11.5 m of sediment that included marine sediment at the top, freshwater sediment in the middle, and marine sediment at the bottom of the core; this suggests that the oldest marine sediment is at least as old as the latest interglacial period (stage 5, about 125 ka). The second core parted at a weld and recovered no sediment. The third core bent and recovered only 4.5 m of sediment, terminating in the middle, nonmarine sediment sequence and providing the first observed evidence of the presence of a freshwater lake feature that once existed in Middle Tampa Bay (box 3–1, fig. 5). Data from these cores were instrumental in providing evidence that Tampa Bay formed as collapsed sinkhole features became inundated with water, rather than as a drowned river valley as previously hypothesized (box 3–1, fig. 6). More information on sediment coring in Tampa Bay is available at *http://gulfsci.usgs.gov*

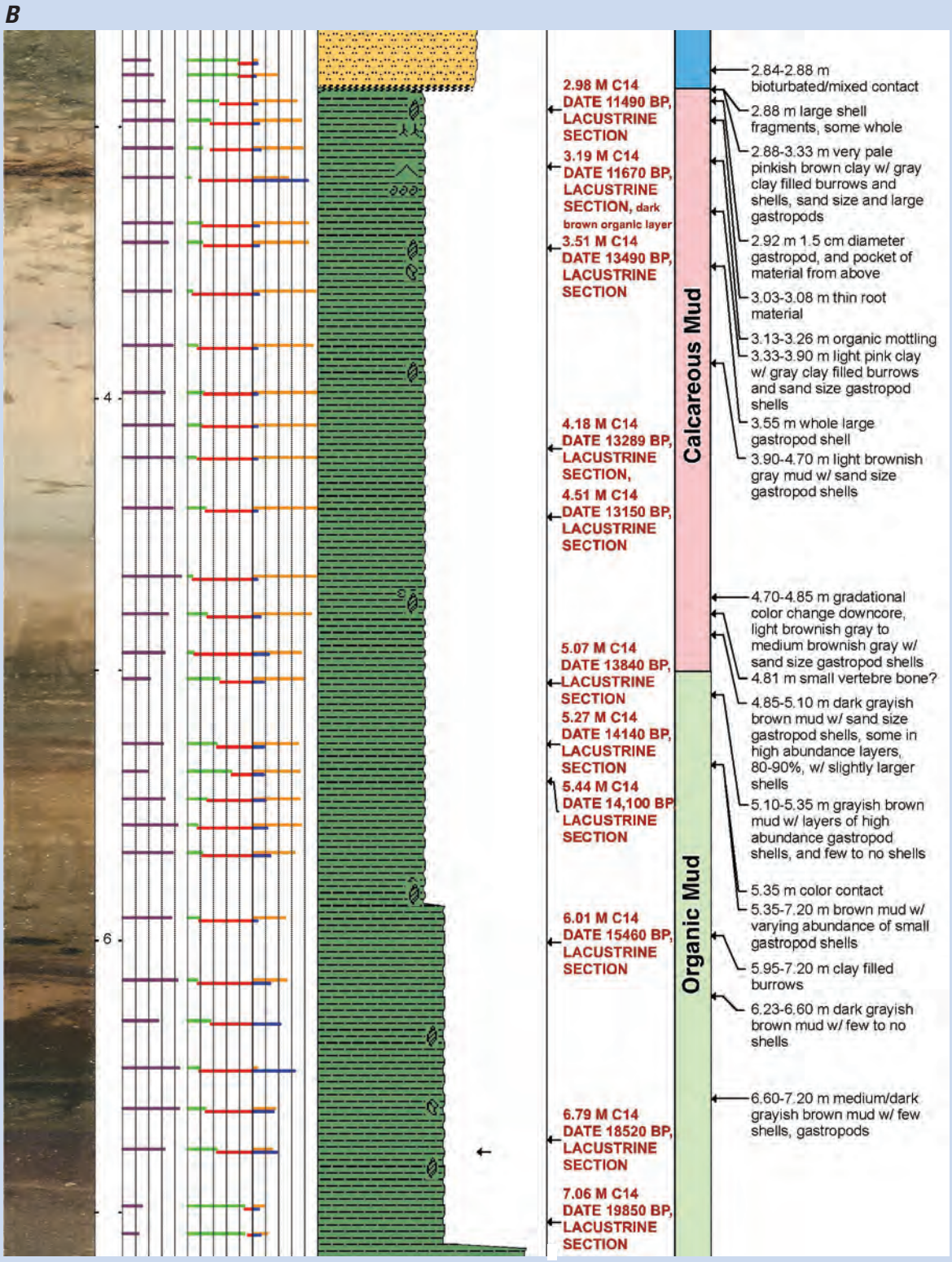
Box 3–1, Figure 3. Research vessel *Marion Dufresne* from which sediment cores were taken in Middle Tampa Bay. Photo from Edgar (2002).

Box 3–1, Figure 4. Core apparatus located on the *Marion Dufresne*, used to take cores from Middle Tampa Bay. Photo from Edgar (2002).

Box 3–1, Figure 5. Bent core pipe retrieved from Middle Tampa Bay while coring from the French research vessel *Marion Dufresne.* Photo from Edgar (2002).

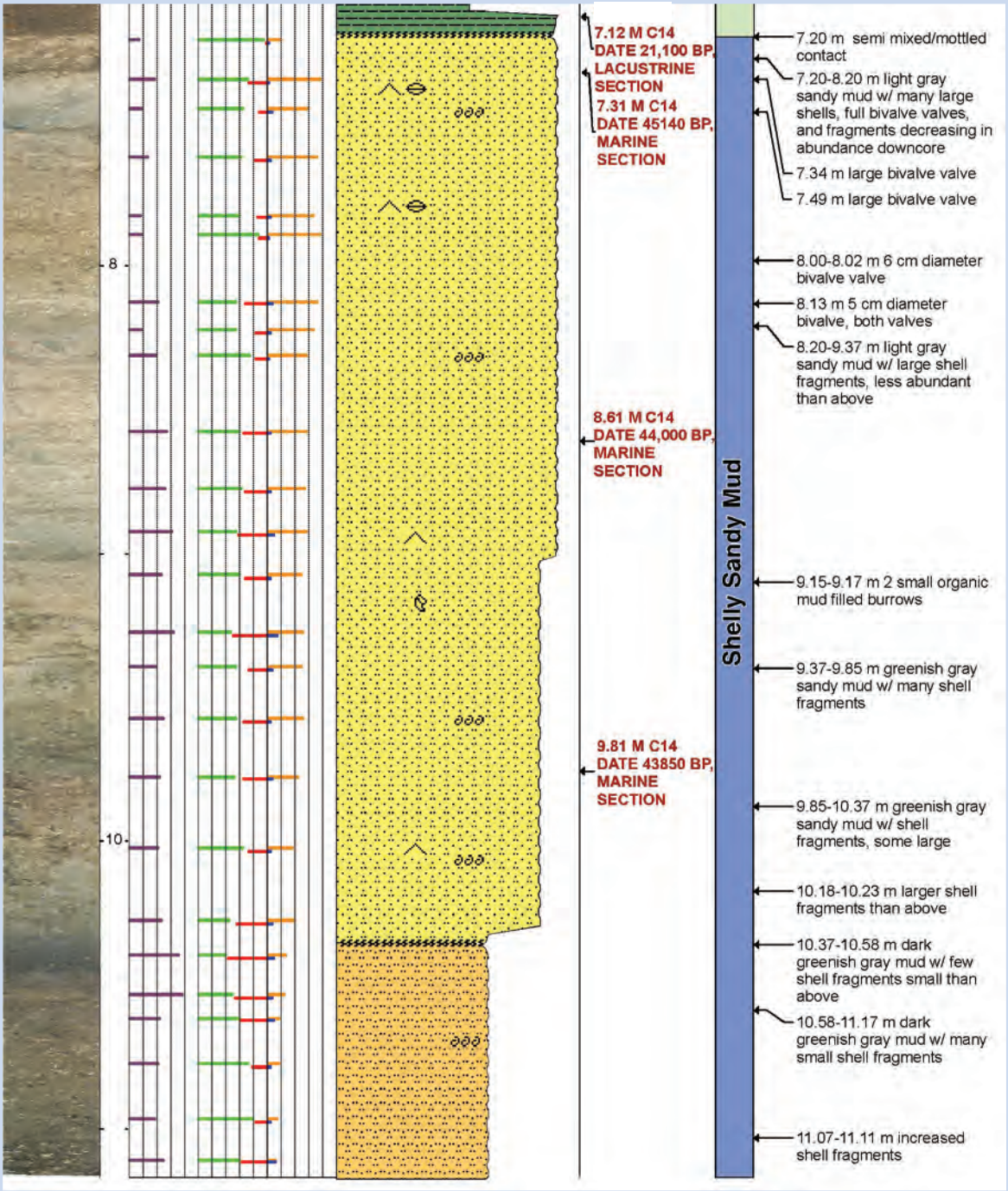


Box 3–1, Figure 6. *A*, Core log describing the 11.5-meter core collected from the *Marion Dufresne*. This stratigraphic sequence was instrumental in determining the origin of Tampa Bay. Core log from U.S. Geological Survey.



Box 3–1, Figure 6. *B*, Core log describing the 11.5-meter core collected from the *Marion Dufresne*. This stratigraphic sequence was instrumental in determining the origin of Tampa Bay. Core log from U.S. Geological Survey.—Continued

C



Box 3–1, Figure 6. *C*, Core log describing the 11.5-meter core collected from the *Marion Dufresne*. This stratigraphic sequence was instrumental in determining the origin of Tampa Bay. Core log from U.S. Geological Survey.—Continued

Geologic History

The Tampa Bay region lies near the center of the Florida Platform, which is a large (up to 350 mi wide and 450 mi long), thick (up to 7 mi in total depth) sedimentary structure that extends southeasterly from the North American continent (Scott and others, 2001; Hine and others, 2003) (fig. 3–1). The modern Florida Peninsula, which represents the part of the platform that is currently above sea level, lies primarily on the platform's eastern side (fig. 3–1). Its bedrock was formed by the deposition of calcium carbonate and other materials from warm, relatively shallow seawater, and contains strata deposited from the mid-Jurassic through the Miocene (fig. 3–5). Between the Jurassic and the late Oligocene, periods of carbonate and siliciclastic deposition occurred in alternating cycles, in response to sea-level fluctuations and changing rates of sediment supply (Scott, 1997). Following the late Oligocene sea-level low stand, sufficient quantities of siliciclastic sediments were transported onto the platform to suppress carbonate deposition, and by the mid-Pliocene, most of the platform was covered by siliciclastics. During the late Pliocene, the sediment supply diminished and carbonate sedimentation was renewed in the southernmost part of the Florida Peninsula (Scott, 1997).

Within Tampa Bay, the karst surface of the Miocene limestone is covered by a layer of quartz sand and other siliciclastic and carbonate sediments that include materials of Miocene (5 to 22.5 Ma), Pliocene (1.8 to 5 Ma), Pleistocene (10 ka to 1.8 Ma) and Holocene (from 10 ka to the present) age (Duncan and others, 2003; Ferguson and Davis, 2003).

The carbonate bedrock of the Florida Platform rests "unconformably" (that is, with a significant time gap) on older basement rocks that range in age from early Paleozoic or Proterozoic (formed more than 500 Ma)

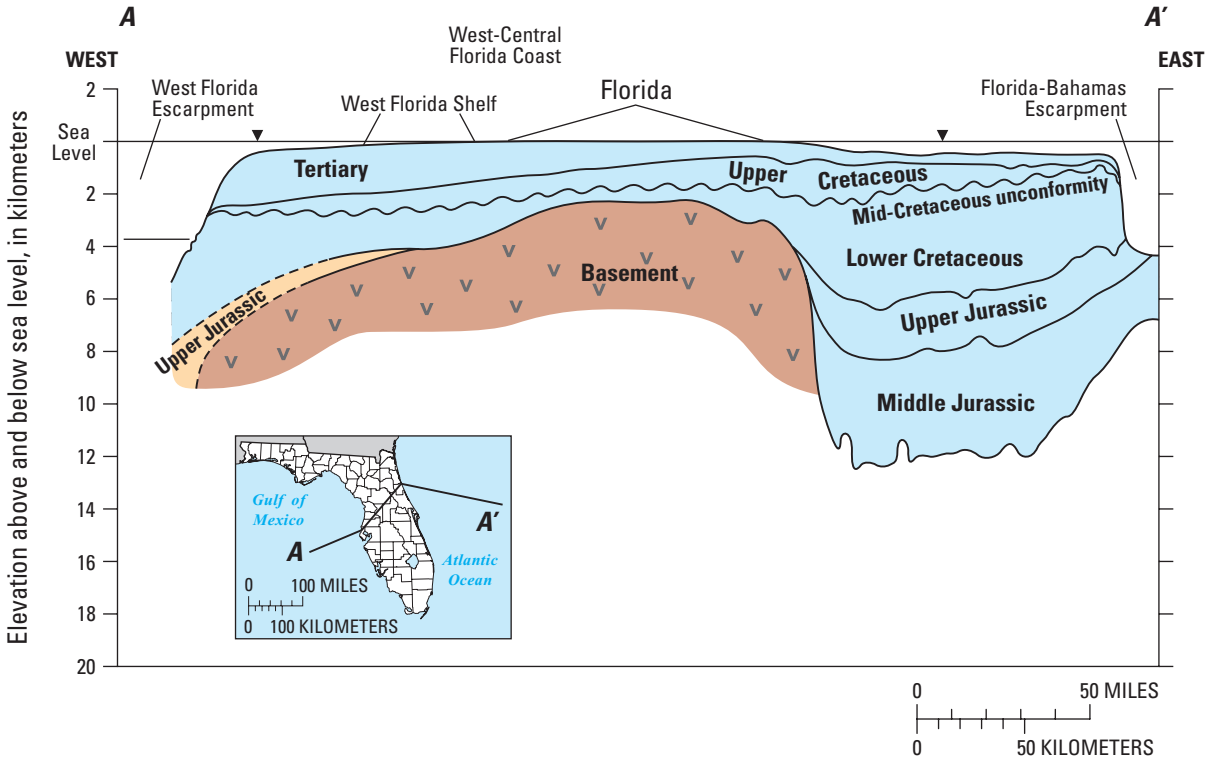


Figure 3–5. Cross-section of the Florida Platform. From Hine and others (2003) with permission from Elsevier.

igneous strata to Ordovician-Devonian (345 to 500 Ma) sedimentary strata to Triassic-Jurassic (about 200 Ma) volcanic strata (Heatherington and Mueller, 1997; Scott and others, 2001). The basement rocks separated from what is now the African Plate when the Pangean super-continent rifted apart, and remained connected to what is now the eastern part of North America as the Gulf of Mexico and central North Atlantic opened during this Late Triassic to Early Jurassic rifting event (Smith and Lord, 1997).

Tampa Bay is located at the western end of a cross-peninsular divide that runs westward from Cape Canaveral (White, 1958; Duncan and others, 2003) (fig. 3–6). The configuration of the underlying Miocene beds changes

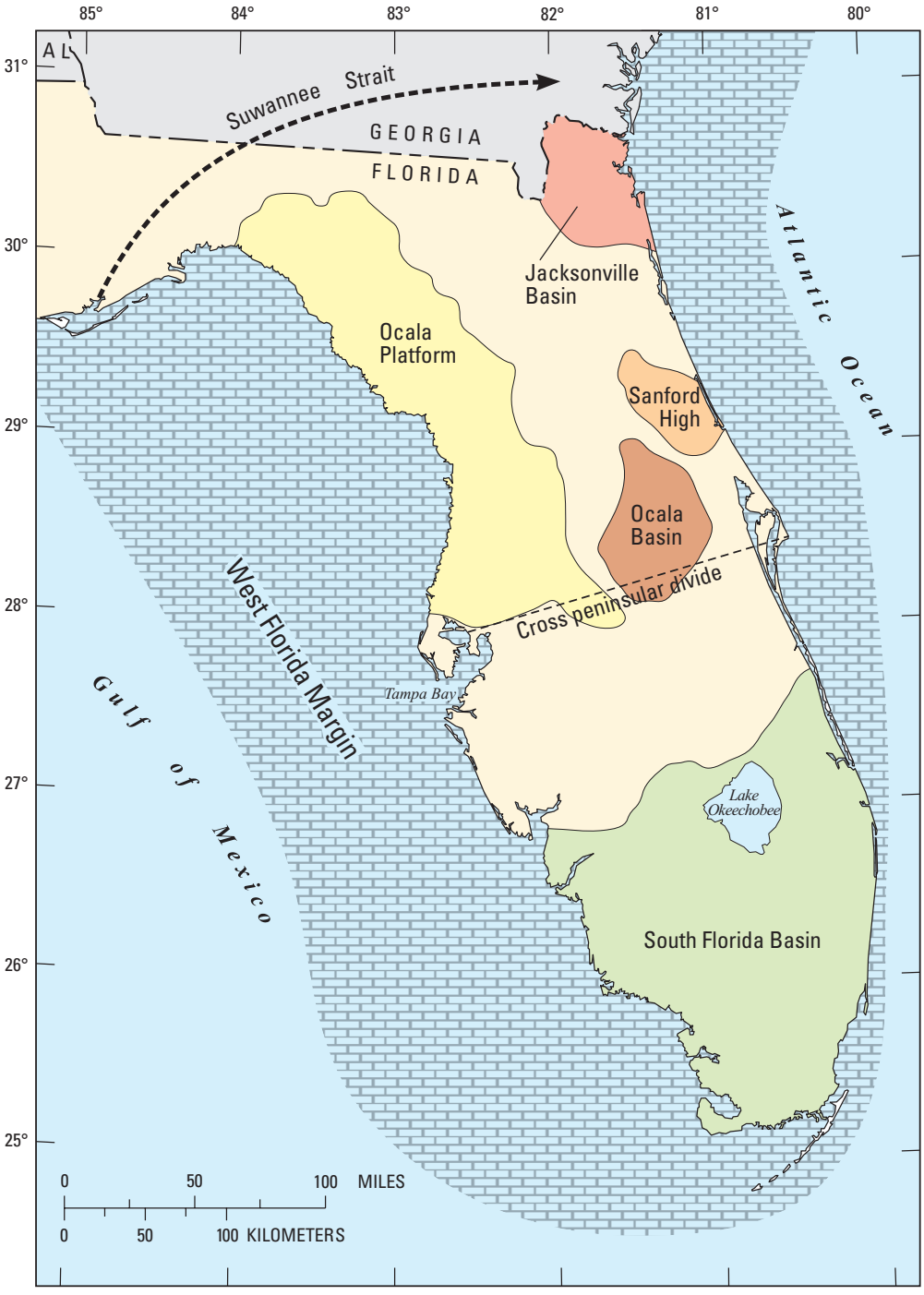


Figure 3–6. Tampa Bay area in a regional context. From Duncan and others (2003) with permission from Elsevier.

along this line, dipping more steeply to the south. The bay is bounded to the north and east by the Ocala Platform, and to the west by the West Florida Margin (Duncan and others, 2003) (fig. 3–6). The Ocala Platform is a structural high, formed in the early Miocene, that trends northwest-southeast across west-central Florida (fig. 3–6). Vernon (1951) proposed that, during the formation of the Ocala Platform, regional tensional stresses were responsible for creating fracture zones visible in aerial photographs. Rectilinear patterns identified in streambed alignments have been attributed to this fracture pattern, which may also have played a role in the geologic evolution of Tampa Bay by providing preferential zones of dissolution/karstification (Duncan and others, 2003).

Stratigraphy

The stratigraphic column underlying Tampa Bay consists of a maximum of about 1.2 mi of carbonates, evaporites and, to a lesser extent, terrigenous clastic sediments (Hine and others, 2009). The area was dominated by carbonate deposition during much of the Paleogene with a shift to a mixed siliciclastic-carbonate regime during the Neogene (Duncan and others, 2003; Ferguson and Davis, 2003). Brewster-Wingard and others (1997) and Scott (1997) developed an updated stratigraphic nomenclature for the units making up the Oligocene/Miocene deposits of west-central Florida, which raises the Hawthorn Formation to Group status and includes within it the Arcadia and Peace River Formations, and the Tampa, Nocatee, and Bone Valley Members (fig 3–7). Based on their regional extent the Arcadia Formation, the Tampa Member of the Arcadia Formation, and undifferentiated siliciclastics are thought to be present in the immediate Tampa Bay area (Scott, 1997; Duncan and others, 2003).

Paleoenvironments

A combination of seismic studies and analyses of sediment cores (see box 3–1) have identified a variety of paleoenvironments that have existed in the area now occupied by Tampa Bay. Duncan and others (2003) collected a dense grid of high-resolution, single-channel seismic data at the mouth of the bay to define the local stratigraphy, determine sediment deposition patterns, and examine the underlying structure of this part of the shelf-valley system, which formed in the early Miocene. Five seismic sequences were identified in the area. These sequences reflect environmental conditions ranging from relatively low-energy deposition dominated by predominantly carbonate sediments within the lowest (mid-Miocene) layer, to higher energy, siliciclastic fluvio-deltaic deposition of late Miocene to Pliocene sediments, to conditions dominated by marine processes (longshore transport, ebb-tidal delta formation) that reworked spatially mixed carbonate-siliciclastic sediments during the Pleistocene and Holocene (table 3–1).

Suthard (2005) and Hine and others (2009) used a similarly detailed but larger data set to give a broader description of the framework of basins and fill underlying the bay. The basins are present on a topographically irregular (>40 m relief) subsurface formed sometime between the deposition

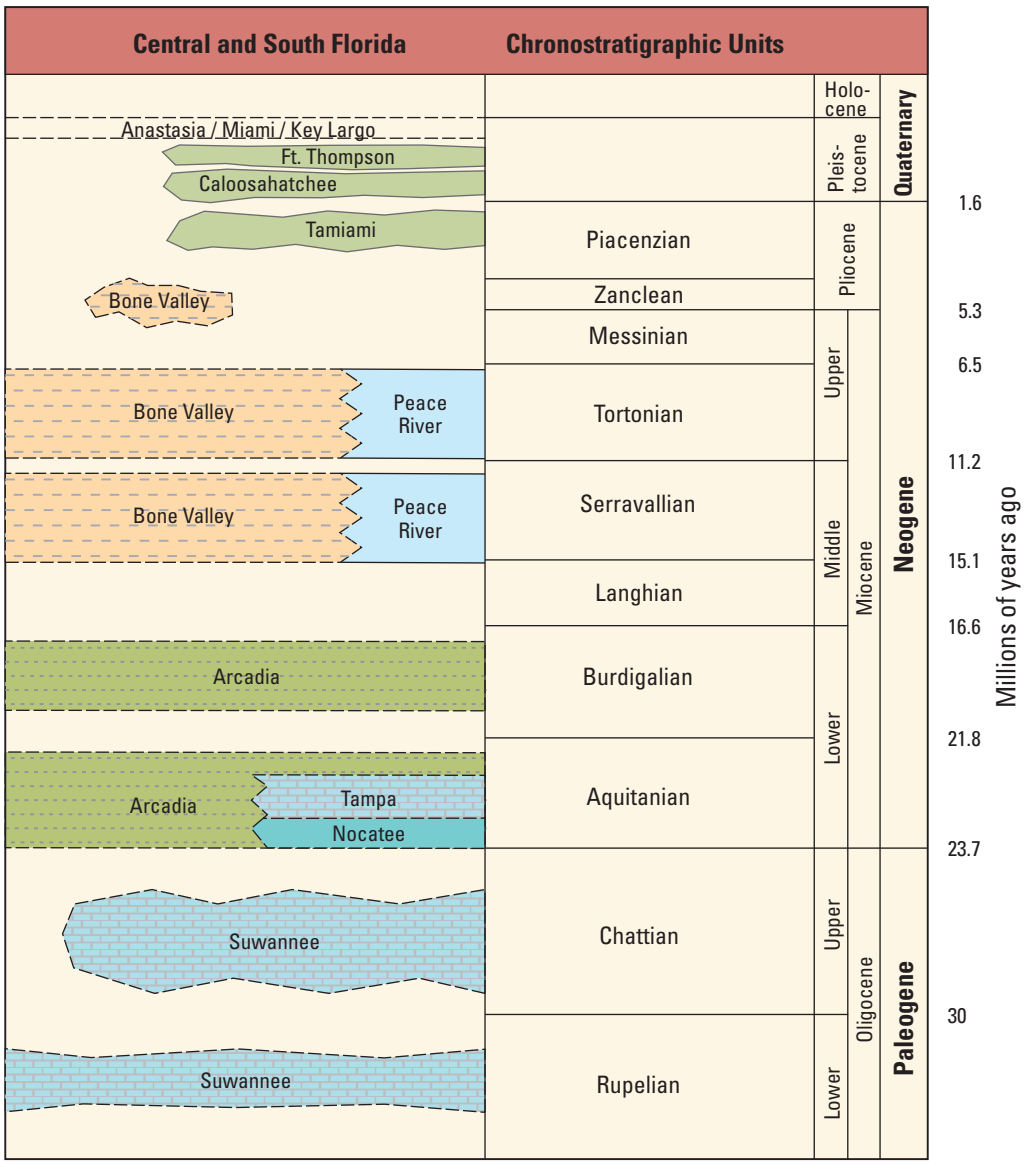


Figure 3–7. Stratigraphic column for central and south Florida. From Duncan and others (2003) with permission from Elsevier.

of the Arcadia Formation limestone (mid-Miocene, open-marine) and the Peace River Formation siliciclastics (mid-to-late Miocene/early Pliocene fluvio-deltaic). They were formed by karst processes that created an irregular topographic low, containing two main deposition centers located in what are now the middle and lower segments of Tampa Bay. The deposition centers were filled by nine distinct sedimentary units during five phases of multiple Neogene and Quaternary sea-level cycles. These deposition centers controlled high-stand and low-stand sedimentary deposition and erosion during the multiple sea-level cycles, and recorded the local deposition of remobilized siliciclastics that were being transported along the Florida Platform (Suthard, 2005; Hine and others, 2009).

Table 3-1. Seismic sequences in strata at the mouth of Tampa Bay.

[m, meter; <, less than. From Duncan and others, 2003]

Sequence	Interpreted age	Thickness	Basal Boundary Character	Seismic Facies	Interpretation	Lithostratigraphy West-Central / South Florida
E	Holocene	0 - 10 m	High amplitude, continuous, where not obscured by bubble pulse	Low reflector amplitude; some high amp. prograding clinoforms near channel.	Recent- ebb-tidal delta and associated coastal deposits	UNDIFF. SANDS AND SILTS
			SB-5			
D	Pleistocene	0 - 10 m	High to med. amplitude; continuous to discontinuous; some channel cuts; karst.	Low to medium reflector amplitude; some high amp. sections; high continuity.	Coastal deposits; possible paleo-ebb-delta.	FT. THOMPSON / CALOOSAHATCHEE / TAMIAMI
			SB-4			
B/C	late Miocene-Pliocene	<3 - 20 m	High amplitude continuous reflector; some channel cuts.	Variable character and configuration; in general weak, continuous reflectors; some high-amp. sections; contains westward progading clinoforms in the north; fill configuration in the south.	Fluvio-deltaic in north; coastal deposits, reworked in central; fill units in south.	BONE VALLEY / PEACE RIVER; BONE VALLEY / PEACE RIVER; LONG KEY EQUIVALENT?
			SB-3			
			High amplitude continuous reflector.			
			SB-2			
A	middle Miocene	<5 - 25 m	Distinct, high-amplitude, continuous reflector in north; low amplitude, discontinuous to absent in south.	North to northwest prograding sigmoidal clinoforms; high-amp.continuous reflectors alternating with low-amp, discontinuous.	High-stand distal delta deposit or high-stand deposits shed to infill basin.	ARCADIA; TAMPA / NOCATEE; ARCADIA
			SB-1			

To provide information on more recent paleoenvironmental changes, Willard and others (2007) examined pollen and ostracode evidence in a sediment core extracted from paleo-lake sediments underlying Middle Tampa Bay. They documented frequent and relatively abrupt changes in climate, hydrologic conditions, and regional vegetation that occurred in the area during a period ranging from 11.5 to 20 ka. The pollen present in the core was enriched in *Chenopodiaceae* sp. and *Carya* sp., indicating much drier- and cooler-than-modern conditions during the last glacial maximum (about 20 ka). Pollen from climatically diagnostic taxa (*Amaranthus australis* and *Pinus taeda*, fig. 3–8) indicating warmer climate conditions increased to between 20 and 40 percent abundance during the initial deglaciation warming about 17.2 ka, and reached near modern abundance (60 to 80 percent) during warmer, moister climates of the Bølling/Allerød interval (12.9 to 14.7 ka). Within the Bølling/Allerød, centennial-scale dry events corresponding to the Older Dryas and Intra-Allerød Cold Period indicate rapid vegetation changes in response to climate variability that occurred over time periods less than 50 years (Willard and others, 2007). For example, order-of-magnitude changes in the relative abundance of forest versus marsh taxa occurred within less than 50 years. The Younger Dryas (11.6 to 12.9 ka) was characterized by two distinct phases: slightly drier than the peak Bølling/Allerød between 12.3 and 12.9 ka, and much drier from 11.5 to 12.3 ka (Willard and others, 2007).

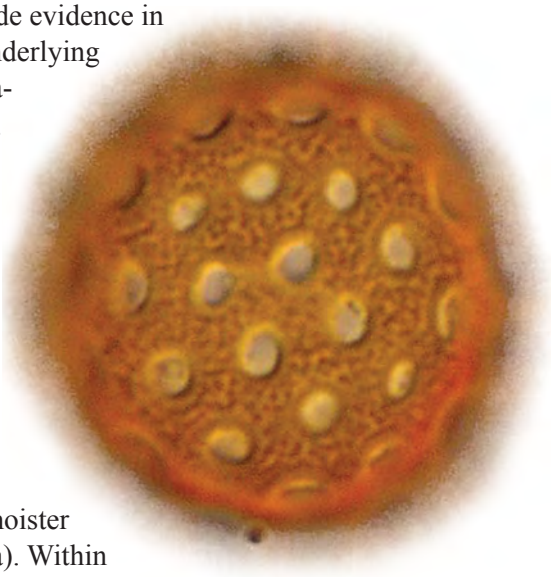


Figure 3–8. Photomicrographs of pollen from two plant species commonly found in Tampa Bay sediments: *above*, *Amaranthus australis* 28 microns in diameter); and *at left*, *Pinus taeda* (about 106 microns from bladder to bladder and 49 microns across the central body). Photo by Deborah Willard, U.S. Geological Survey.

Anthropogenic Changes to the Bay and its Watershed

As noted in Chapter 1, the human population of the Tampa Bay watershed began a period of rapid increase in the late 1940s and early 1950s (fig. 1–5). Accompanying this growth, a number of urban centers, including the cities of Tampa, St. Petersburg, Clearwater, and Bradenton, were constructed on or near the bay shoreline.

To support coastal urban development, dredge-and-fill techniques were used in several areas to remove sediment from shallow parts of the bay and deposit the material as fill along the shoreline. A number of causeways and bridges, residential communities, powerplants, port facilities, and other commercial and industrial infrastructure were constructed using these techniques (fig. 2–1) (Janicki and others, 1995). An extensive network of shipping channels was also constructed. These were dredged to depths of 13 m, and extend from the bay mouth to several port, harbor, and industrial facilities located in Hillsborough Bay, Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay (fig. 2–1; see also box 2–1)

For areas within and immediately adjacent to the bay, this construction activity peaked in the 1950s and 1960s, causing substantial changes to the bay's bathymetry, tidal prism and flushing characteristics (Goodwin, 1987), and impacting an estimated 12,800 acres of environmentally sensitive shallow-water habitats (TBEP, 2006). About 5,100 acres of Boca Ciega Bay (26 percent of that bay segment's historical shallow water area) were filled for residential and commercial development. Large areas of the shallows in Old Tampa Bay (2,800 acres; 9 percent) and Hillsborough Bay (1,900 acres; 24 percent) were filled or channelized for urban and port development.

Regional urbanization has also affected the ecological and hydrologic characteristics of the watershed, through the removal of natural upland and wetland habitats and their associated plant and animal species, and the construction of roads, parking lots, sidewalks, rooftops, and other impervious surfaces. These surfaces shed rainwater rather than allowing it to soak into the ground, thus decreasing groundwater recharge and increasing the volume of stormwater runoff that is generated by a given rainfall event. The total runoff volume discharged by a one-acre parking lot, for example, is about 16 times larger than the volume generated by an undeveloped meadow (Schueler and Holland, 2000).

Impervious surfaces also collect contaminants that are deposited from the atmosphere, and from vehicles and other sources, which are easily washed off and transported to receiving waterbodies during rain events. Monitoring and modeling studies indicate that contaminant loads discharged from urban and suburban catchments to receiving waters are directly related to the percentage of the catchment that is covered by impervious surfaces (Schueler and Holland, 2000). In a number of studies around the United States, degradation of streamwater quality and living resources has been observed in areas with relatively low levels of imperviousness (about 10 percent). Estimated changes in impervious surface area in the Tampa Bay watershed during 1991–2002 are shown in fig. 3–9. Some of the effects of these anthropogenic changes on Tampa Bay, as recorded in the bay's sediments, are described in box 3–2.

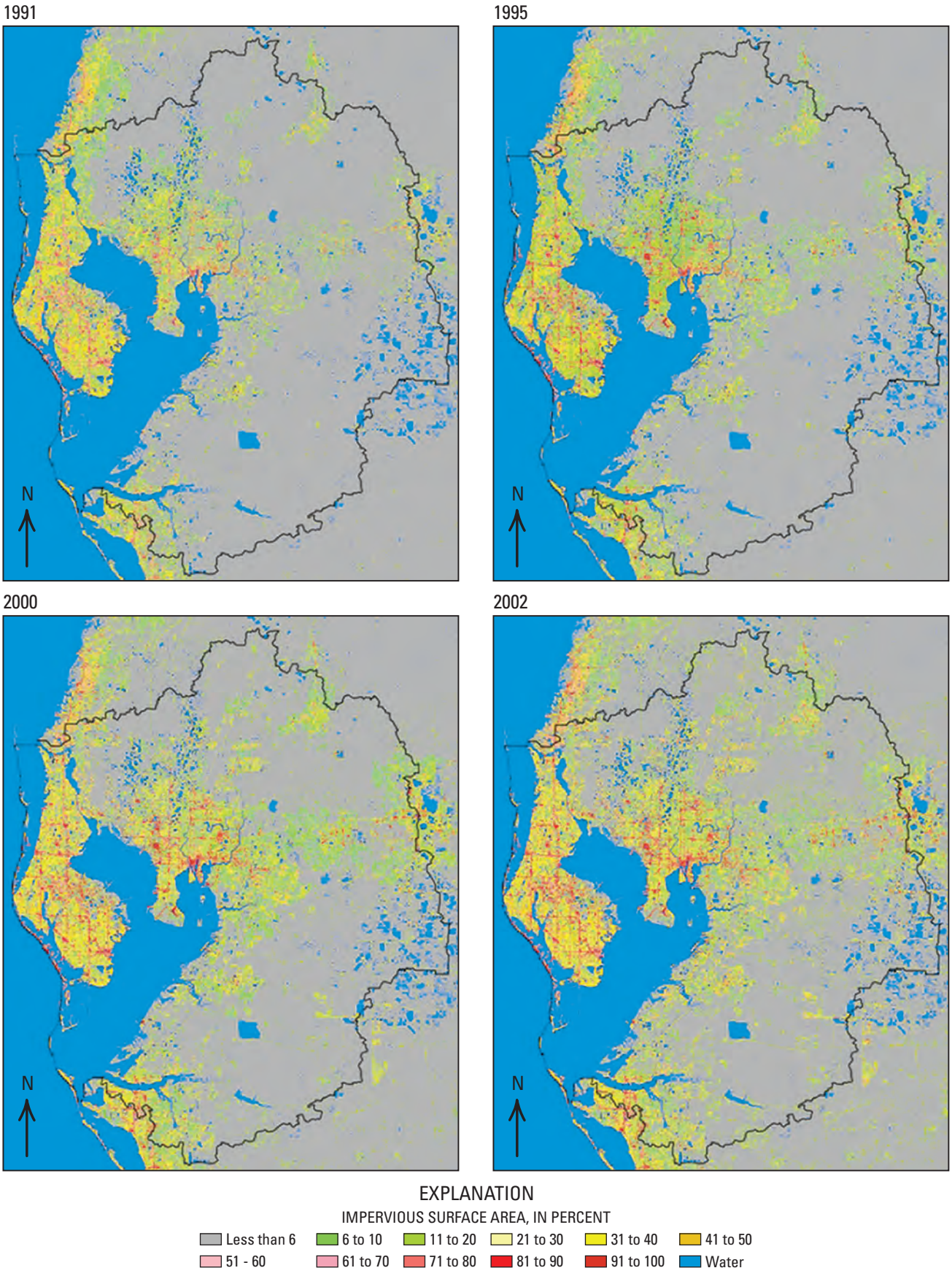


Figure 3–9. Estimated impervious surface levels in the Tampa Bay watershed for 1991, 1995, 2000, and 2002. From Xian and Crane (2005) with permission from Elsevier.

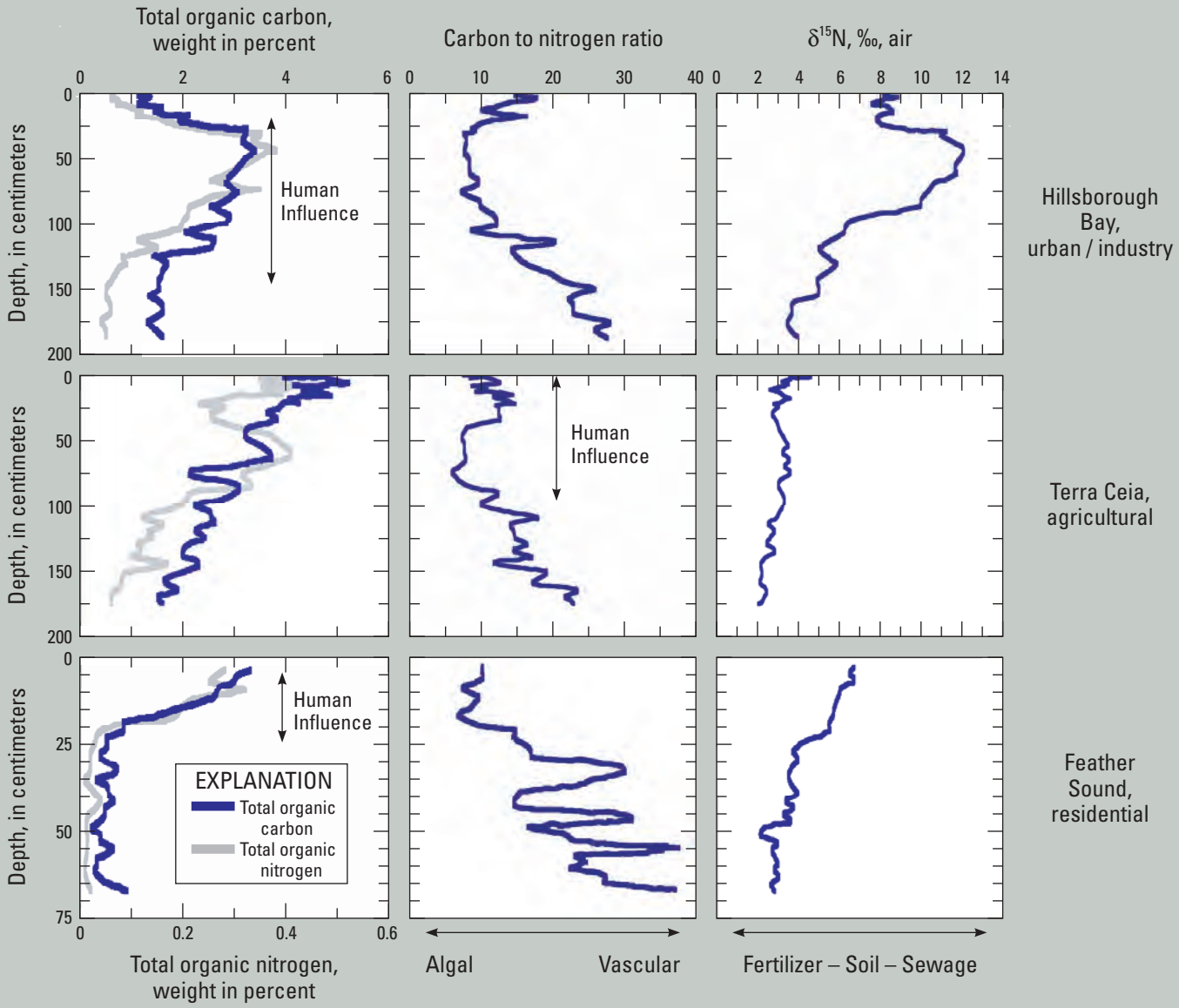
Box 3–2. Sedimentary Indicators of Human Effects on Tampa Bay

Excerpt from Yates and others (2006)

As part of the USGS Tampa Bay Study, the sedimentary record of Tampa Bay was examined for evidence of human influences on ecosystems during the past century (Yates and others, 2006). Comparative molecular organic geochemistry and stable isotopes were used to investigate a suite of sediment cores from relatively pristine (for example, Terra Ceia) and highly anthropogenically altered (for example Hillsborough Bay, Feather Sound, Safety Harbor, Bishop Harbor, and Lake Maggiore) regions of the bay. Results from this study were used to reconstruct and evaluate changes in carbon and nitrogen (N) cycling, and population dynamics and bioassemblage succession of upland plants, macrophytes, and phytoplankton. Using precisely dated sediment cores, the geochemical records were correlated with historical records of changes in land use, nutrient loading, contaminant input, and the distribution and abundance of estuarine fauna (mangroves, sea grasses, and other macrophytes), surface-dwelling plankton populations, and terrestrial plant ecosystems. Preliminary results indicate that sediment cores from Old Tampa Bay (Feather Sound and Safety Harbor areas), the city of St. Petersburg (Lake Maggiore), Hillsborough Bay, Central Bay, and Terra Ceia contain a well-preserved sediment archive, recording the most recent anthropogenic influences. All sites show significant changes in N cycling. Terra Ceia, Feather Sound, and Hillsborough Bay sites are located adjacent to watersheds dominated by agricultural, residential, and urban/industrial land uses, respectively, and effects from these land uses are reflected in the cores (box 3–2, fig. 1). Organic carbon and N concentrations have increased at all sites, with Hillsborough Bay sediments showing a 15-fold increase in N during the past 100 years. Sediments from Safety Harbor show a 5-fold N increase whereas those from Terra Ceia show a 3-fold increase during the past 100 years. The timing of the increase in organic carbon and N concentrations, indicating a transition from vascular plants to algal sources of organic matter in the cores, coincides with the increase in human impacts to the different regions. This reflects the strong anthropogenic influence in these areas.

Analyses of the N isotopic composition of organic matter reflect a dominant input from terrestrial plant material. In Hillsborough Bay, recent sediments show a transition to values up to 12‰, reflecting increased contributions from treated wastewater, septic inputs, or N contributions from livestock. In Terra Ceia, agricultural development in the watershed is reflected in the N isotopic composition of the recent sediments, which have an isotopic signature associated with the use of atmospheric N_2 for the synthesis of agricultural nutrients. Feather Sound displays intermediate values (+6 ‰), reflecting a combination of inputs from soil-derived N and treated wastewater. All sites also show significant changes in carbon cycling, including a recent 8-fold increase in carbon at Safety Harbor and Feather Sound, a 30-fold increase at Lake Maggiore, and a 2 to 3-fold increase in Central Bay and Hillsborough Bay.

Carbon isotopic composition of the organic matter reveals significant changes in biogeochemical cycling of carbon and the widespread development and influence



Box 3–2, Figure 1. Weight percent total organic carbon and total organic nitrogen, elemental atomic carbon to nitrogen ratio, and $\delta^{15}N$ composition of sedimentary organic matter in three sediment cores from Hillsborough Bay, Terra Ceia, and Feather Sound. From Yates and others (2006).

of anaerobic recycling processes. For example, in Lake Maggiore, carbon isotopic composition shifted over 20‰ in association with the historical record of nutrient loading and the relative importance of bacterial recycling processes associated with progressive lake eutrophication. Molecular organic geochemical studies reveal that, prior to anthropogenic changes to the aqueous and upland environments surrounding Safety Harbor and Central Bay, the distribution of organic compounds was strikingly similar; this suggests that both sites were once influenced by the same biological, chemical, and physical processes.

Of particular note is the selective onset of anaerobic conditions in the most recent sediments in Safety Harbor and Lake Maggiore. Molecular distributions indicate that the development of anoxic conditions is coincident with enhanced input of labile organic matter attributable to algal, zooplankton, and sewage sources. The biological and chemical consequences and overall environmental implications associated with the onset of anaerobic sedimentary conditions are significant because of the potential for remobilization of toxic metals, release of carcinogenic organic contaminants, and deterioration and absolute demise of the benthic floral and faunal communities. Other effects of human activities on the ecology, hydrology, water and sediment quality, and living resources of the bay and its watershed are discussed in more detail in Chapters 6, 7 and 8, below.

A follow-up sediment characterization study was performed in the Safety Harbor area by the USGS, in cooperation with the Tampa Bay Estuary Program (TBEP), Southwest Florida Water Management District (SWFWMD), University of South Florida (USF), and Eckerd College, in 2008–2009. Project objectives were to develop a 3-D map of the extent and volume of organic-rich sediment accumulation in Safety Harbor, to determine the origin of recent and historic sediment accumulations, and to investigate the ecological context of accumulations of organic-rich sediments. Results indicate that highly organic “muck” sediments are currently accumulating in three areas, the central part of the Harbor, dredged areas, and nearshore areas landward of shallow shoals. The muck has been accumulating more rapidly in recent years, and may be influenced by changes in circulation (associated with bridge construction and the Lake Tarpon Outfall Canal) and nutrient loading from the watershed. It is primarily the remains of microscopic algae and small crustaceans that live in the water column. Isotope ratios indicate that the source of nutrients for these organisms has changed over time, with inorganic fertilizer serving as an increasingly important N source in recent decades (Peebles and others, 2009).

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