The Gulf Coast of Florida : Overview of Physiography, Geology, and Historical Shoreline Change

By James H. Balsillie and Ralph R. Clark

March 1992

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A Report of the
FLORIDA DEPARTMENT OF NATURAL RESOURCES
DIVISION OF BEACHES AND SHORES

March 1992

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INTRODUCTION

The Florida peninsula is the emergent portion of a larger extension of the North American continent named the Floridian Plateau that is comprised of sedimentary rocks which have accumulated on top of deeply-lying igneous and metamorphic basement rocks. Surface sediments range from Tertiary to Recent in age, and are primarily the result of climatic fluctuations occurring during the Pleistocene Epoch, two million to 10,000 years before present. These Pleistocene climatic changes, resulting in worldwide sea level changes, are primarily responsible for Florida's coastal physiography. Presently, except for the Apalachicola River entering the Gulf of Mexico near the east part of the Panhandle Gulf Coast, rivers of Florida do not contribute appreciable quantitities of sand-sized sediment to the State's coasts.

The State of Florida has over 1,202 km [747 mi] of shoreline fronting directly upon the Gulf of Mexico of which about 671 km [417 mi] are sandy beaches. Of the sandy beaches, 309 km [192 mi] are currently experiencing problematic erosion, of which 163 km [101 mi] are considered critical, and 146 km [91 mi] noncritical (Clark, 1991a). In addition, there are at least 5,030 km [3,125 mi] of bay and estuarine shoreline. Not counting river entrances of the Big Bend and tidal channels of the Ten Thousand Islands, lower Everglades and the Florida Keys, sandy beaches of the Gulf are affected by 55 barrier tidal inlets resulting, on the average, in an inlet for every 12 km [7 mi] of beach.

Typically, Florida's Gulf coast beaches have long-term historical erosion rates (see the Table) of less than 0.5 m/yr. Many problem areas have erosion rates on the order of 1.5 m/yr, with an extreme erosion rate of 7 m/yr occurring along the southern part of St. Joseph Peninsula (Figure 1). Most of Florida's beach erosion problems, particularly critical erosion, have resulted from stabilization, construction, and development of barrier tidal inlets (Figure 2). Many of the natural undeveloped inlets, being dynamic in their behavior, are also responsible for causing adjacent shoreline shifts viewed to be erosion. Of the 55 barrier beach tidal inlets along the Gulf, 36 have not been altered by man (i.e., no jetties and no maintenance dredging). Of the remaining, 19 have been dredged to maintain navigation channels, 17 have been fitted with jetties or terminal groins, and 11 have bridges crossing them. To mitigate shoreline erosion conditions adjacent to inlets, inlet sand transfer projects have been conducted at 21 Gulf inlets to nourish adjacent beaches. Coastal armoring, too, can complicate long-term shoreline behavior. However, except for Panama City Beach along the panhandle Gulf coast and those highly developed barrier islands of the lower Gulf coast, Florida's Gulf coastal regions are generally devoid of such structures.

The geology, physiography and erosional history of Gulf Coast Florida, however, is highly variable. To

Table of shoreline and beach lengths and beach erosion data for the Gulf of Mexico coast of Florida

County or Region	Ocean-Fronting Coasts: Shoreline Length (Miles)	Ocean-Fronting Coasts: Beach Length (Miles)	Bay and Estuary Shoreline Length (Miles)	Length of Noncritical Beach Erosion (Miles)	Length of Critical Beach Erosion (Miles)	Total Length of Beach Erosion (Miles)
PANHANDLE GULF COAST						
Escambia County	38.9	38.9	126.8	12.3	4.9	17.2
Santa Rosa	5.0	5.0	120.6	1.9	0.0	1.9
Okaloosa	23.9	23.9	88.8	1.7	0.0	1.7
Walton	25.6	25.6	66.0	0.0	0.0	0.0
Bay	41.2	41.2	226.4	14.3	11.6	25.9
Gulf	28.8	28.8	43.6	16.8	0.1	16.9
Franklin	54.6	54.6	171.8	16.3	2.0	18.3
Panhandle Gulf Coast Totals	218.0	218.0	844.0	63.3	18.6	81.9
BIG BEND GULF COAST						
Wakulla	≃24.8	2.5	75.2	0.0	2.0	2.0
Jefferson	≃6.3	0.0	?	0.0	0.0	0.0
Taylor	≃51.8	0.0	?	0.0	0.0	0.0
Dixie	≃23.8	0.0	?	0.0	0.0	0.0
Levy	≃59.2	2.0	?	1.2	0.0	1.2
Citrus	≃28.4	0.2	?	0.0	0.0	0.0
Hernando	≃22.6	0.8	?	0.0	0.8	0.8
Pasco	≃22.0	1.4	?	0.0	0.2	0.2
Big Bend Gulf Coast Totals	≃238.9	7.4	75.2	1.2	3.0	4.2
LOWER GULF COAST						
Pinellas (includes all of Anclote Key)	40.2	40.2	228.0	4.9	20.9	25.8
Hillsborough	2.1	2.1	187.0	2.1	0.0	2.1
Manatee	12.3	12.3	176.0	0.0	7.0	7.0
Sarasota	34.7	34.7	121.0	0.0	19.1	19.1
Charlotte	12.2	12.2	218.0	1.4	4.4	5.8
Lee	47.3	47.3	278.0	8.3	16.9	25.2
Collier North County Line to Cape Romano	34.1	34.1	≈700.0	9.8	10.8	20.6
Lower Gulf Coast Totals	182.9	182.9		26.5	79.1	105.6
TEN THOUSAND ISLANDS						
Collier	≈12.0	?		?	?	?
Monroe	≈12.0	?	≈297.0	?	?	?
Ten Thousand Islands Totals	≈24.0	?		?	?	?
LOWER EVERGLADES COAST						
Monroe and Everglades Total	≈50.0	?		?	?	?
FLORIDA KEYS						
Monroe						
Lower Keys	≈16.5	1.2		?	?	?
Outer Keys	2.6	0.0		?	?	?
Marquesas Keys	9.9	2.5		?	?	?
Dry Tortugas	6.7	4.5		?	?	?
Florida Keys Totals	≈33.0	8.2		?	?	?
Gulf Coast Totals	746.8	416.5	3124.2	91.0	100.7	191.7

NOTES:

1. Bay and Estuary Shoreline Length is from the *National Shoreline Study* (U. S. Army, 1971).
2. All other shoreline length data from Balsillie, Carlen and Watters (1987a, 1987b).
3. Erosion reaches from Clark (1991).
4. ≃ indicates a close estimate; ≈ "as the crow flies" measurement; ? indicates data are not available.

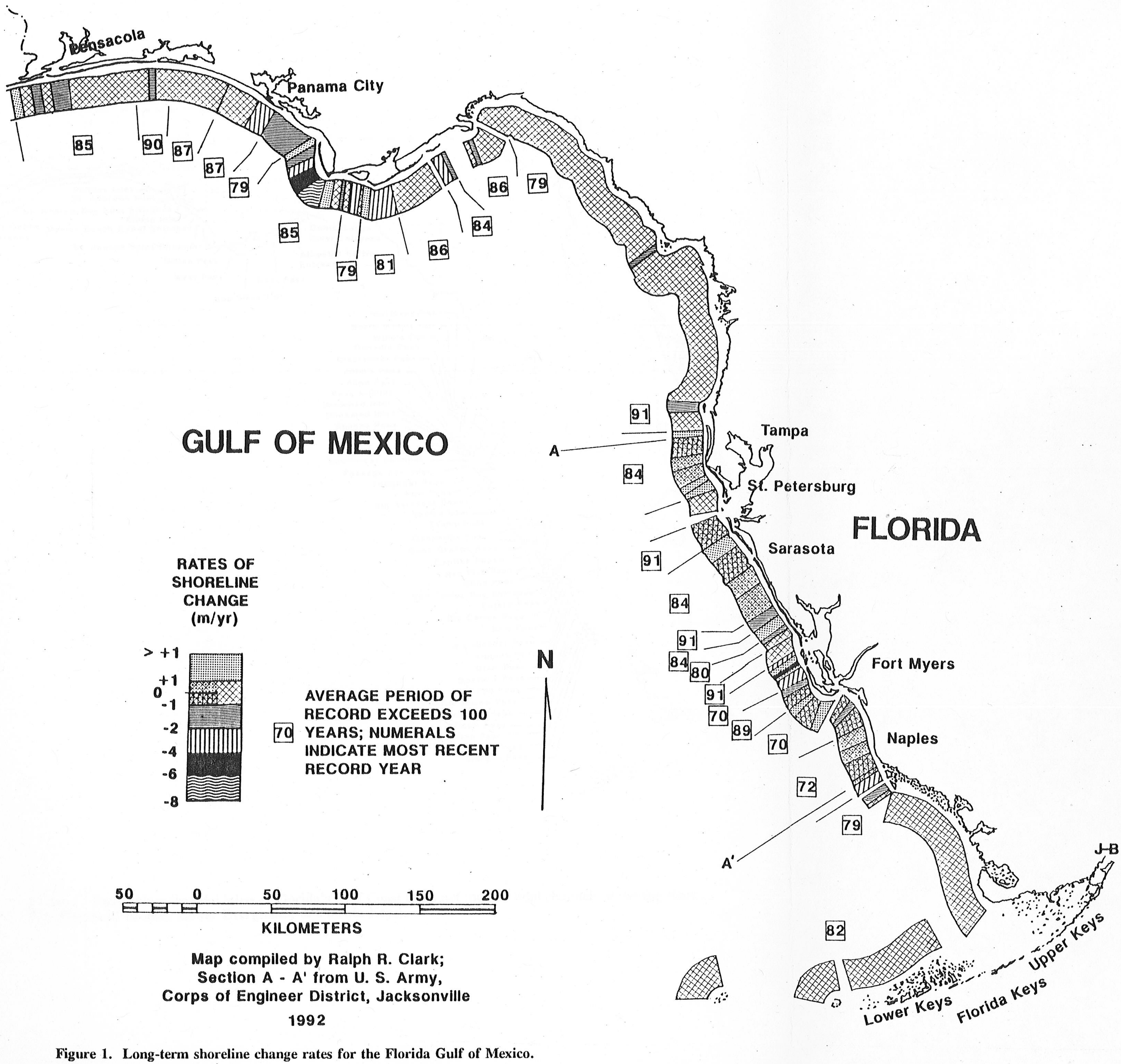

Figure 1. Long-term shoreline change rates for the Florida Gulf of Mexico.

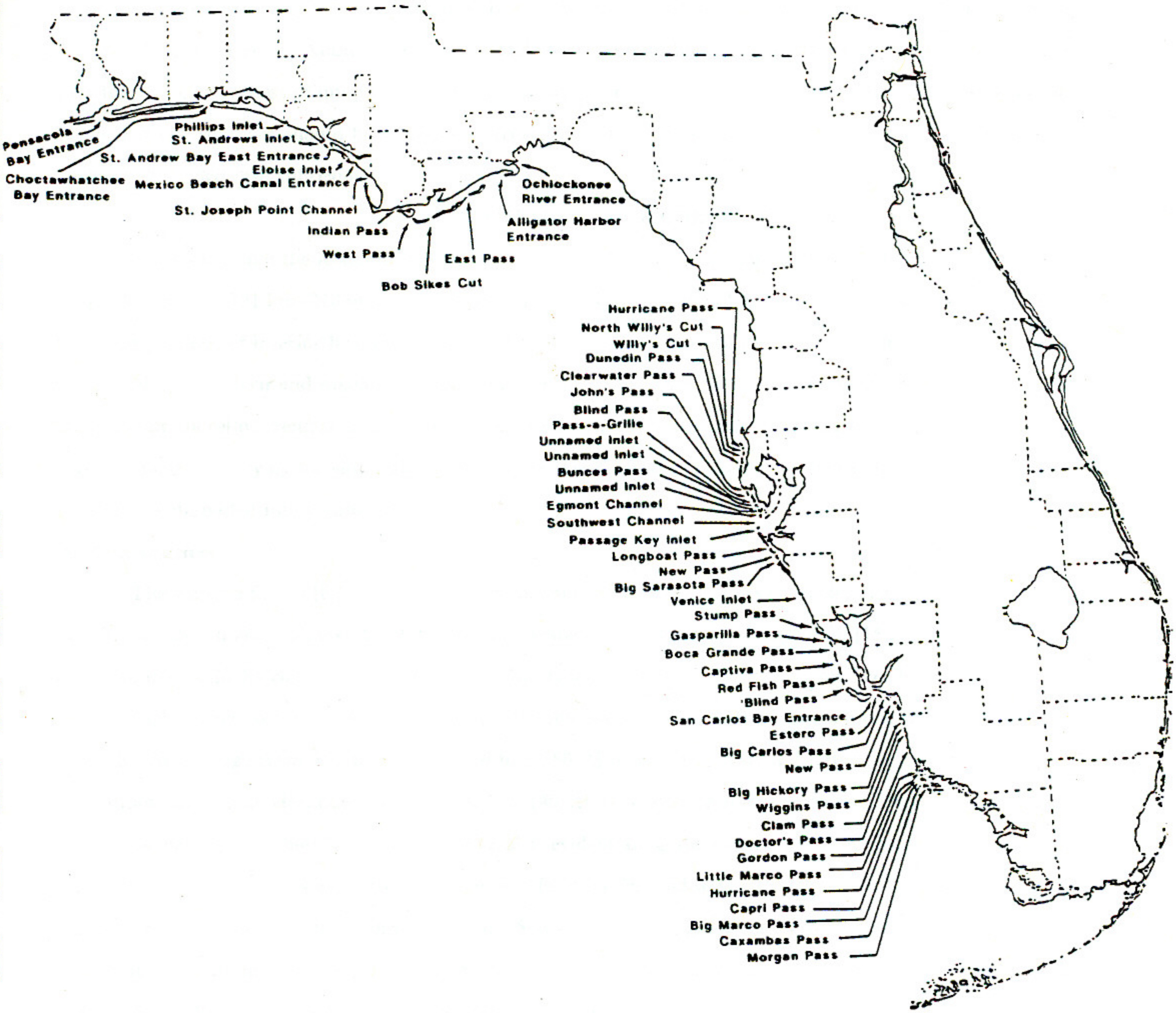

Figure 2. Coastal barrier tidal inlets of Florida's Gulf Coast (does not include tidal channels of the Big Bend, Ten Thousand Islands, Lower Everglades, or Florida Keys).

facilitate more efficient discussion, Florida's Gulf Coast is, here, divided into 6 general regions (Figure 3). From northwest to southeast these are the Panhandle, Big Bend, Lower Gulf Coast, Ten Thousand Islands, Lower Everglades, and the Florida Keys. Additionally, as coastal development pressures increase, so do pressures concerning knowledgeable awareness of unique coastal environments, so that we recognize the need for special considerations with which that environment should be respectfully treated. For this reason, the 6 general regions are for the most part further subdivided into subregions.

PANHANDLE GULF COAST

Extending from the Alabama-Florida state line on the west to the mouth of the Ochlockonee River to the east, the panhandle has 351 km [218 mi] of sandy Gulf-fronting beaches and 13 barrier tidal inlets. There are, in addition, 1,358 km [844 mi] of interior bay and estuarine shoreline. On the basis of general shoreline shape, the panhandle can be divided into western and eastern segments, divided roughly in the vicinity of St. Andrews Bay East Entrance. To the west, the shoreline trend is arcuate but smooth; to the east shoreline azimuths change abruptly with peninsulas and barrier islands of varying physiographic form. On the basis of other general physiographic factors, each segment can be further subdivided into 2 subsegments.

Western Barriers

The western 98 km [61 mi] of the western portion of the panhandle is characterized by two barrier islands and interspersed beach ridge plains. Perdido Key, the westernmost island, is about 24 km [15 mi] in length of which 20.3 km [12.6 mi] lie in Florida. To the east of Perdido Key and separated by Pensacola Bay Entrance, lies Santa Rosa Island which, being 76.8 km [48 mi] in length, is the longest unbroken barrier island along the Gulf coast of Florida. These barriers range from 150 to 1000 m [500 to 3,250 ft] in width with dune heights averaging +5 m [17 ft] MSL (maximum dune crest elevations of up to +12 m [40 ft] MSL can be found). Net sediment transport along these barriers is westward, although a west-east reversal is evident along the eastern tip of Perdido Key (Stone, 1991; Stone *et al.* 1992). Erosion occurs along the eastern end of Perdido Key and western end of Santa Rosa Island (Balsillie, Chiu and Demirapolat, 1986) ranging from about 1 to 1.5 m/yr [3 to 5 ft/yr], and has been attributed to historical, repetitious overwashing during hurricanes (Stone and Salmon, 1988) and an increasing wave energy gradient particularly along western Santa Rosa Island (Stone, 1991; Stone *et al.* 1992).

Middle Mainland

To the east of Santa Rosa Island and East Pass (Choctawhatchee Bay) lies a 81.5 km [50.6 mi] reach of late Pleistocene mainland coast, an unusual feature in Florida coastal physiography (Balsillie, 1975), which Tanner (1960) attributes to high nearshore ramp slopes. Back beach primary dunes along this mainland reach attain elevations of from 3.5 to 13.7 m [12 to 45 ft] and beach widths average 60 m [200 ft] (Fischer *et al.* 1984). Upland coastal terrain is drained by a number of streams flowing to the Gulf from a series of small to medium-sized freshwater lakes. These seasonal outlets are periodically closed due to predominantly westward longshore sediment transport (e.g., Stone, 1991).

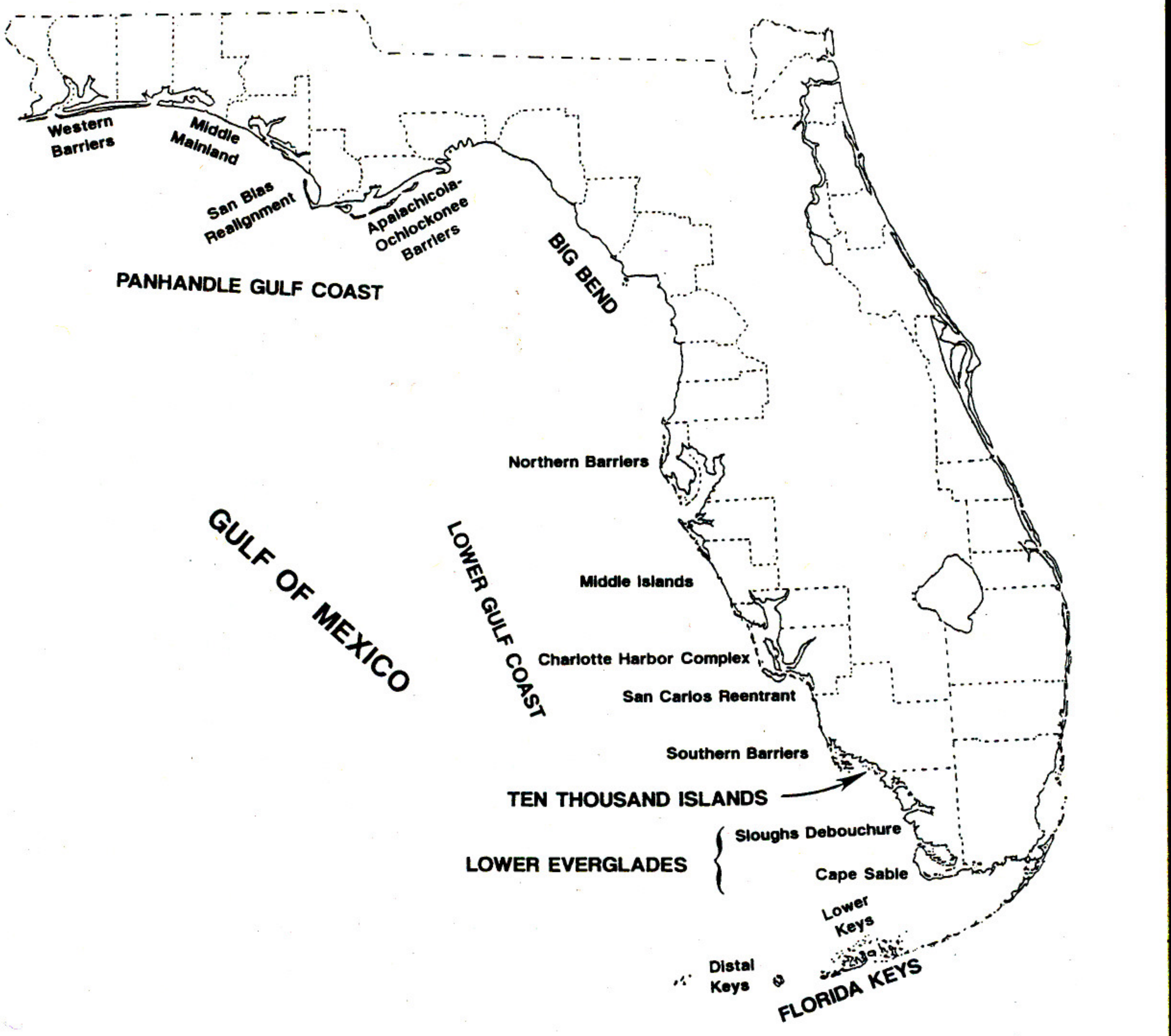

Figure 3. Physiographic regions and subregions of Florida's Gulf of Mexico coast.

With the exception of relatively short reaches of slight, noncritical erosion near Navarre Beach and just east of East Pass, the reach extending 57 km [35.5 mi] west of East Pass to 52 km [32.3 mi] east of East Pass, is the longest (109 km total) stable segment of beach along the Gulf coast of Florida. However, because of its well developed dunes, extreme event impacts have resulted in significant dune erosion and coastal recession (e.g., Chiu, 1977; Balsillie and Clark, 1979; Balsillie, 1985c, 1986). Phillips Inlet near the eastern end of the mainland segment is an intermittent tidal connection to the brackish Lake Powell. East from Lake Powell, the shore is characterized by mainland beaches to the vicinity of Panama City Beach where a barrier spit has formed, trending to the southeast across the entrance to St. Andrews Bay. This barrier spit has been bisected by the dredging of an artificial channel (St. Andrews Inlet) for navigation into St. Andrews Bay, creating Shell Island which extends to the east for about 10 km [6.2 mi]. Net longshore transport of the panhandle west of the inlet is to the west with reversals occurring on a sub-seasonal time framework (Balsillie, 1975, 1977). West of St. Andrews Inlet the barrier spit ranges in width from about 395 to 460 m [1,300 to 1,500 ft], while Shell Island to the east ranges in width from 180 to 1,220 m [600 to 4,000 ft]. Net westward longshore transport from St. Andrews Inlet and the historic practice of periodically depositing channel maintenance dredging material offshore has resulted in critical erosion for 11 km [7 mi] west of the inlet. Historical erosion reaches a maximum of 2.4 m/yr [8 ft/yr] about 1.8 km [1.1 mi] west of the inlet (Balsillie, O'Neal and Kelly, 1986). Stapor (1973a) identified a drift divide just east of St. Andrews Inlet with net easterly transport occurring along most of Shell Island. Measured erosion rates (Balsillie, O'Neal and Kelly, 1986) along the island range between 0.5 m/yr [1.74 ft/yr] to 2 m/yr [6.4 ft/yr].

San Blas Realignment

To the east and south of Shell Island and St. Andrews Bay East Entrance lies the eastern portion of the panhandle Gulf coast. Immediately east of Shell Island is an area of confluence of two longshore transport cells. To the southeast, along Crooked Island, net longshore transport is to the northwest. Southeast of Crooked Island is another mainland reach along which net transport is to the southeast (Stapor, 1973a). St. Joseph Peninsula to the south, 27 km [17 mi] in length, is a north-south trending barrier spit of recent geological age. The spit extends west from the mainland for about 5 km [3 mi] where it forms Cape San Blas. St. Joseph Peninsula ranges in width from less than 180 to 1,400 m [600 to 4,600 ft] and is subject to overwash and breaching along several narrow reaches. Primary dunes range in height from 1.5 to 11 m [5 to 37 ft] with beach widths ranging from 21 to 152 m [70 to 500 ft]. Except for the northern 3.5 km [2.2 mi] which is accreting, the peninsula is eroding (Stapor, 1971; Tanner, 1975; Balsillie, 1985a; Clark, 1991a), with the most extreme erosion rate fronting the Florida Gulf coast occurring at Stump Hole along the southern part of the peninsula just north of Cape San Blas at 7 m/yr [31 ft/yr] (Balsillie, 1985a). Cape San Blas lighthouse has been relocated 6 times to eastern sites since its original construction (Tanner, 1975). Sensitivity of shoreline change to storm tides and wave conditions has been witnessed during 2 hurricanes in 1985 when 762 m

[2,500 ft] of the southward projecting cape disappeared (Clark, 1986). An alongshore drift divide has been identified somewhere along the southern 1/3 of St. Joseph Peninsula (Stapor, 1971) with St. Joseph Point (north end of the feature) accreting northward due to erosion north of the divide, and southerly transport south of the divide contributing sand to the extensive shoals off of Cape San Blas.

Apalachicola-Ochlockonee Barriers

To the east of Cape San Blas, the coast line now trending in an east-west direction, historical rates of accretion are as high as 20 m/yr [61 ft/yr], suggesting a significant net eastward transport of Cape San Blas sediment controlled by wave refraction due to shoal configuration and shoreline geometry. The mainland segment spans 4.6 km [2.9 mi] of coast east to Indian Peninsula, a 4.8 km [3 mi] eastward extending spit. East of Indian Peninsula and separated by Indian Pass lies St. Vincent Island a triangularly shaped barrier which, about 12 km [7.5 mi] long, is comprised of a unique complex of multiple beach ridges trending generally southeast to east-southeast. The St. Vincent beach ridge plain is almost 6.5 km [4 mi] wide, containing 12 beach ridge sets with about 189 individual beach ridges (Stapor, 1973b; Stapor and Tanner, 1977; Campbell, 1986). To the east, and separated from St. Vincent Island by West Pass is the barrier island complex of Little St. George and St. George Islands which is about 47 km [29 mi] long and ranges from 335 to 1,600 m [1,100 ft to 1 mi] in width. From West Pass to Cape St. George, Little St. George Island has the same southeasterly orientation as St. Vincent Island and is comprised of about 35 parallel beach ridges. Little St. George was once a separate island that is now part of St. George Island. At Cape St. George, the island changes orientation trending in a northeasterly direction. Along an approximate 10.5 km [6.5 mi] reach of western St. George Island, erosion appears to exceed 2 m/yr [6.5 ft/yr]. Westerly directed net longshore transport occurs along this erosional reach which is bisected by a small man-made jettied inlet (Bob Sikes Cut). East of St. George Island and separated by 3.2 km [2 mi] wide East Pass lies Dog Island, the easternmost coastal barrier island in the northern Gulf of Mexico. Irregularly shaped Dog Island is 11 km [6.9 mi] long with narrow western and broad eastern segments. Two low and narrow areas along the western portion of the island are less than 150 m [500 ft] wide and subject to inundation and breaches from even moderate storm tide impacts; the eastern segment attains a width of about 1,300 m [4,300 ft]. Net longshore transport is bidirectional along the island with the dominant transport occurring westward toward the narrows and opposing eastward transport near the broadest reach. Long-term historical erosion trends suggest a maximum erosion rate of over 2 m/yr [6.5 ft/yr], although more recent trends suggest an acceleration in the erosion rate of perhaps 6 m/yr [20 ft/yr] (Clark, 1986). The easternmost segment of the panhandle region is a mainland peninsula, known as St. James Island, which lies between the Gulf and Ochlockonee Bay. The eastern end of the peninsula extends in a north-south orientation for a distance of 5.5 km [3.4 mi] from Bald Point southward to Lighthouse Point. From Lighthouse Point, a recent (Holocene) barrier spit extends for about 8 km [5 mi] to the west past Southwest Cape and terminating in Alligator Point. Net longshore transport is to the west along the barrier spit. The reach between Southwest Cape and Lighthouse Point constitutes perhaps the most critical erosion reach along the panhandle. Severe erosion and costly property and structural damages have been incurred by a number of storms during the past 30 years (Clark, 1986).

BIG BEND GULF COAST

The Big Bend, here, is defined as the low to zero wave energy shore (Tanner, 1960) stretching for some 149 km [240 mi] from Ochlockonee Bay on its western end, east and south to Anclote Key just north of Tampa. It is unique because of its marsh-dominated open-marine character, very wide shallow shelf fronting it, highly crenulated shoreline shape with 1000's of creek outlets and embayments, and sedimentology restricted to organics and carbonate constituents with only minimal silici-clastic sediments (Hine *et al.* 1988). Concerted geological exploration of the Big Bend is just beginning (e.g., Hine and Belknap, 1986; Hine *et al.* 1988) with a cooperative effort just organized by geologists and marine scientists of the University of South Florida, Florida Geological Survey, and the U. S. Geological Survey. Of the 390 km of shoreline (measured "as the crow flies"), only 11.9 km [7.4 mi] have quartz sand beaches. Mashes Sands (a chenier) just north of the Ochlockonee Bay entrance (Clark, 1991b), Shell Point along the northern extremity of the Big Bend, and the Cedar Keys (including Seahorse Key and North Key) and Pine Island along the eastern flank of the Big Bend, represent the major localized deposits of quartz sand beaches along the reach. Of the 11.9 km of beach Clark (1991a) reports that 6.8 km [4.2 mi] are experiencing erosion, of which 4.8 km [3 mi] are critical and 1.9 km [1.2 mi] are noncritical.

LOWER GULF COAST

The barrier islands of the lower gulf coast constitute a near continuous chain extending from Anclote Key to the north to Cape Romano to the south, a distance of 295 km [183 mi]. Barriers have not formed to the north of Anclote Key due to the lack of sand and low wave energy. While there is one sound (7.7 km [4.8 mi]), one mainland reach (5.6 km [3.5 mi]), and what appears to be an upland coast of reliction (17.6 km [11.1 mi]), there are 41 inlets which is indicative of the number of barrier islands to be found along the lower Gulf coast. The majority of the lower Gulf coast is characterized as having moderate wave energy shores (Tanner, 1960), although northern and southern areas grade to low wave energy. However, a significant characteristic of the reach is that calm seas prevail for up to 30% of the annual period (termed "zero wave energy component").

Northern Barriers (Anclote Key to Tampa Bay)

Until recently, the lower Gulf coast was one of the least studied coasts in the nation. While much of this region as yet requires study, the coastal barriers north of the entrance to Tampa Bay have undergone extensive geophysical studies. From Anclote Key, the northernmost coastal barrier to Egmont Key at the entrance to Tampa Bay, there are 14 barrier islands and 11 tidal inlets. Origins of the barriers have been described as transgressive, landward migrating features of an unknown mode of formation (Riggs and O'Conner, 1974) and, more recently, to have an upward shoaling mode of formation (Brame, 1976; Rosen, 1976; Davis and Kuhn, 1985) controlled by the underlying rock topography (Hine *et al.* 1986). With no new sediment being supplied to the beaches, these coastal barriers are comprised of a relatively thin sand lens lying on top of Tertiary limestone; in the Gulfward direction the sand lens thins and pinches out within 500 m [1,600 ft] of the beach (Davis *et al.* 1982; Evans *et al.* 1985). Of the barriers, Three Rooker Bar, and North and South Bunces Keys, are the youngest having evolved within the past 20 years. Since 1980, at least 5 inlets have naturally opened while 3 others have closed. Most of the islands are erosional with at least 45 km [28 mi] of the 68.7 km [42.7 mi] of beach (about 65%) considered to be erosion problems (U. S. Army, 1984a, 1984b; Clark, 1991a). Net longshore transport volumes are slight and generally to the south, although local reversals do occur (e.g., Balsillie and Clark, 1992). Sand Key, the longest barrier island north of Tampa Bay with 22.9 km [14.2 mi] of beach, is the site of several beach restoration projects; also restored are beaches of Treasure Island and Long Key lying to the south of Sand Key.

Middle Islands (Tampa Bay to Charlotte Harbor)

From Tampa Bay entrance south to the north side of Charlotte Harbor, a distance of about 98 km [61 mi], lie a series of 9 low-lying barrier islands which for the most part are long and narrow. Wave energy is moderate (Tanner, 1960), and longshore transport except for localized influences of some inlets is to the south. Near the middle of the reach, just to the south of Venice Inlet lies a 5.6 km [3.5 mi] long mainland beach. Lido Key, near the north central part of the area, is a man-made island which has also been an area receiving beach renourishment, while Don Pedro Island was within recent times 4 separate keys. Of particular interest along Siesta Key, to the south of Lido Key lies Point O'Rocks with a 550 m [1,800 ft] ledge of rock (probably belonging to the Hawthorn Group, Tom Scott, personal communications) extending into the surf. Outcrops of the mid-Miocene Hawthorn Group are exposed along Venice beach from which the beach and nearshore receive an abundance of fossilized sharks teeth. These exposures suggest potential subsurface control. Seismic profiling north of Tampa Bay Entrance (Davis and Kuhn, 1985) and in the Charlotte Harbor area (Evans and Hine, 1986) indicate that the pre-Quaternary surface is an irregular, karstic surface, and that "... the location of barrier islands and hence tidal inlets is at least partly controlled by this irregular bedrock topography" (Gibeaut and Davis, 1988), and that the coastal barriers and beaches are comprised of a relatively thin layer of fine quartz sand with only limited seaward extent. However, such extrapolation can be made only in the most generalized sense, since the reach as yet requires geological investigation. Longshore transport volumes are slight and generally to the south. Clark (1991a) has determined that 51 km [32 mi] of beach (52% of the total beach length) along this reach is currently experiencing problematic erosion (U. S. Army, 1980, 1984c, 1984d, 1991a, 1991b,). Beach restoration is being conducted along the central part of Anna Maria Island (the northernmost key) and other projects are planned for Longboat Key and Venice.

Charlotte Harbor Complex (Charlotte Harbor to San Carlos Bay Entrance)

From the northern extent of Charlotte Harbor at Gasparilla Pass south, a distance of 59.5 km [37 mi], lies an arcuate sequence of 5 coastal barrier islands separated from the mainland by the wide bodies of water of Charlotte Harbor, Pine Island Sound, and San Carlos Bay. Within Pine Island Sound lies Pine Island a large feature, to the south and about which curves Sanibel Island, the southernmost island of this Gulf-fronting coastal barrier island group. These islands range in length from 6.6 to 21 km [4.1 to 12.9 mi] and in width from 60 to 4,000 m [200 to 13,000 ft], and have peak coastal elevations of from 1 to 3 m [3 to 10 ft] (Fischer *et al.* 1984). Wave energy is moderate (Tanner, 1960). Longshore transport processes operate within a series of partially integrated cells (Harvey, 1979). Geologic seismic investigations have revealed that underlying karstic, fractured, and antecedent Tertiary carbonate rocks controlled subsequent sedimentation as affected by repeated Quaternary sea level fluctuations causing coastal systems to migrate through the area. The current barrier island configuration is perched upon one of the Pleistocene platforms, the details of which are discussed by Evans *et al.* (1989). These Holocene barriers (history chronicled by Stapor *et al.* (1987) employing c^{14} and beach ridge analyses) began to prograde seaward about 4,400 years ago (Stapor and Mathews, 1980). This time frame corresponds with late Holocene sea level rise reduction that, combined with a local sand supply and pre-existing topography, played a key role in the location, initial growth, and formation of the present barrier island chain (Hine, 1987). While the sedimentary environment is currently dominated by siliciclastic sediments, the proportion of carbonate shell fragments is significant and relatively rare in the southeastern U. S. These sediments have formed the beach ridges by both longshore and onshore sediment transport processes (Stapor *et al.* 1987). Even so, high resolution geophysical studies are needed to determine the depth and extent of particulate sand volumes comprising these barriers as well as their offshore extent. It has been determined that 27.4 km [17 mi] of Gulf-fronting beaches of these barriers are experiencing problematic erosion (Clark, 1991a; U. S. Army, 1969; Coastal Planning and Engineering, 1989). The erosion areas are largely confined to the north end of Sanibel Island and islands to the north, with the southern 17.6 km [11 mi] of Sanibel Island being stable to accreting; note, however, that the entire length of Captiva Island's (lying just to the north of Sanibel Island) beach has been restored.

San Carlos-Estero Reentrant (San Carlos Bay Entrance to Gordon Pass)

The coast from just south of San Carlos Bay south to Wiggins Pass, a distance of 46.7 km [29 mi], is unique by virtue of its gradational change in physiography from north to south. The northern 20 km [12 mi] of the reach is characterized by a group of low-lying, narrow islands, of which all but two are small, tightly-packed, and mobile. The reach contrasts with barrier islands to the north because: 1. it is sheltered from northwest approaching waves by Sanibel Island, and 2. bays behind the coastal barriers are much smaller and, hence, so are the associated 5 inlets (Hine, 1987). The bay backing the coastal barriers becomes gradually, but distinctly constricted toward the south where it losses physiographic continuity just to the south of Wiggins Pass. Continuing south to Doctor's Pass, some 10 km [6.4 mi], the coast embodies a line of small, discontinuous back-beach water bodies (except where dredged for marinas), which might be characteristic of a coast of reliction. The southern 7.6 km [4.7 mi] of the reach from Doctor's Pass south to Gordon Pass, while approaching the status of a true mainland coast, may be more aptly described as a more mature upland coast of reliction continuing from the north (particularly in view of development of the City of Naples). Wave energy is moderate to low (Tanner, 1960) with longshore transport small in volume and to the south except for reversals along the northern part of the reach. While beaches along the reach are continuous they are narrow, and Clark (1991) reports that 26 km [16.2 mi] of beach are experiencing problematic erosion due not to a high rate of shoreline change but due to the degree of threat to adjacent development resulting from the slow erosion of these narrow beaches (U. S. Army, 1972).

Southern Barriers (Gordon Pass to Cape Romano)

To the south of Gordon Pass, the coast is again characterized by a chain of 6 recognized barrier islands with at least 8 tidal inlets (inlets frequently open and close along this segment). This southernmost reach of the lower Gulf coast extends south a distance of about 32 km [20 mi]. Wave energy is low (Tanner, 1960), with slight net longshore transport to the south except for local reversals. With the exception of Marco Island's restored beaches, the beaches of this segment are narrow with about 65% (20 km [12.5 mi]) of the total beach length currently experiencing problematic erosion (U. S. Army, 1972; Clark, 1991a). These coastal barrier islands constitute the southernmost extent of significant amounts of accumulated siliciclastic sediments.

TEN THOUSAND ISLANDS

Appropriately named, this remote group of essentially uncharted islands are concentrated along 39 km (24 mi "as the crow flies") of Florida Gulf coast reaching from the lee of Cape Romano south to Pavilion Key and occupying a coastal band about 6.4 km [4 mi] in width. White (1970) notes that the reach differs from sections both north and south and seems to be a gradation between them. Those islands of the group fronting directly on the Gulf, built over the past 3,000 to 5,000 years, are the result of vermetid reefs (Shier, 1969). These colonizing reefs formed the core of the outer islands, which have trapped quartz sand transported across Gullivan Bay from shoals south of Cape Romano (Davis, 1940; Scholl, 1964; Shier, 1969). More interior disposed islands are long, narrow, and twisted oyster bars and indian middens (Parkinson, 1989) which to some extent entrap sediments. Both low-lying island types are vegetated by mangroves and lie atop bedrock limestone of the Tamiami Formation. (Lane, 1981). Changes in shoreline configuration of the Gulf-fronting islands of the Ten Thousand Islands has never been monitored. However, based on geological evidence Shier (1969) has noted that storms and hurricanes have caused erosion and that during the past 3 centuries more exposed vermetid reefs have been eroded away faster than vermetid growth could build new reef. While the outer islands maintain themselves by mangrove and sand migration on the lee side of the islands, they have moved "bodily" toward the mainland. In the absence of any monitoring and quantitative information, one might suggest, from the geological evidence, that erosive forces are slowly at work.

LOWER EVERGLADES GULF COAST

This remote and unique coastal segment extends some 80 km [50 mi] from the vicinity of Pavilion Key at the south end of the Ten Thousand Islands, southeast to East Cape. It is the southwest terminus of drainage of the Everglades and Big Cypress Swamp. The entire reach is characterized by low wave energy which increases to the south. Coastal surface sediments are exclusively carbonate (mud and shell) which, overlying the Miami Formation, extend to depths of 3 to 4.5 m below mean sea level and give way to peats and fresh-water carbonates in the landward direction (Roberts *et al.* 1977).

The Sloughs Debouchure

It is thought that at one time the entire lower Everglades reach was more homogeneous in physiography and mangrove vegetation similar to that found along Florida Bay. However, over about the past 3,000 years, erosion along the northern portion of the reach and southerly directed longshore transport has resulted in a retreating shoreline (Gleason *et al.* 1974) along the northern 65 km [40 mi] and deposition along the southern 15 km [10 mi]. The northern area, which White (1970) termed the "debouchure of the Everglades Sloughs" with its numerous mangrove islands and tidal creeks, is largely characterized by low-lying steep mud banks vegetated by a fringing mangrove forest up to 200 m in width, and by a few discontinuous narrow beaches of carbonate shell sediments (note, however, that beaches along this reach have not been inventoried). The mangrove forest, attaining heights of 15 m, is distinctly zoned with red mangroves along the shoreline and black and white mangroves in the upland forest interior. This coast has never been monitored to determine quantitative rates of shoreline behavior and although it is known to be subject to erosion, no quantitative rate of erosion is available.

Cape Sable

Along the southern 15 km of the reach, lies Cape Sable, the best developed regressional physiographic feature on the south Florida coast. The cape prograded up to 8 km (5 mi; Enos and Perkins, 1979), achieving its present status about 1,200 to 1,500 years ago (Roberts *et al.* 1977). Cape Sable is comprised of three capes (Northwest Cape, Middle Cape, and East Cape, the latter of which also faces Florida Bay and is the youngest feature, with Northwest Cape being the oldest; Smith, 1968). The capes are composed of shell beaches with a spatial dispersal pattern and physiography indicating southeastward longshore transport, and are linked by narrow shell beaches. Older beach ridges lie behind the beaches and are composed of carbonate-mud material (Gleason *et al.* 1974), and are vegetated with succulents, grasses and palms with the most landward ridges having a dense hammock vegetation (Roberts *et al.* 1977). Cape Sable beaches have not been monitored to determine quantitative rates of shoreline behavior, and even information to ascertain a qualitative guess at the stability of the reach is not available.

FLORIDA KEYS

The Florida Keys which stretch for over 354 km [220 mi] are an elongated, arcuate shaped archipelago separated from the mainland by Florida Bay, a broad but shallow water body compartmentalized by numerous carbonate mud banks. The keys were formed as the result of the last major drop in sea level which exposed the ancient coral reefs. Those keys considered to front directly on the Gulf of Mexico include the northern shores of the "lower keys" and the three distal sandy island groups to the west. The "upper and middle keys" front not on the Gulf, but on Florida Bay and the Straits of Florida and are comprised of the coralline limestone of the Key Largo Formation. Corals comprising the formation were flourishing during the Pleistocene as a line of patch reefs in the backreef area of a broad reef platform (Multer, 1971). As sea level fluctuated during the Pleistocene the Key Largo limestone accumulated up to 200 feet in thickness (Lane, 1986). The "lower keys", lying between the Gulf of Mexico and the Straits of Florida, however, differ geologically from the "upper and middle keys" because the Miami Formation overlays the Key Largo Formation. The carbonate Miami Formation is an oolitic facies which began accumulating during the late Pleistocene when sea level conditions were favorable for carbonate sand bank accumulation behind the outer reef, to become exposed as the "lower keys" when sea level dropped.

Lower Keys

Although the most significant carbonate beaches and dunes of the "lower keys" front on the Straits of Florida, several locally significant beaches are found along the "back country" islands of the "lower keys" fronting the Gulf. Carbonate sedimentation here is due to the entrapping capability of marine grasses and algae. Beach sediments consist primarily of calcareous green algae, limestone fragments, and a variety of mollusks and foraminifera (Jindrich, 1969). Such beaches found along Mud Key, Snipe Point (Snipe Key), Marvin Key (Barracuda Keys), Sawyer Key, and the Content Keys, total about 1.9 km [1.2 mi] in length and average 8 m in width. Coastal processes have not been documented for these beaches, but it is thought that the direction of net annual longshore sediment transport is to the southwest.

Distal Keys

Beaches of the 3 island groups west of Key West have not been studied except in terms of general physiography (Davis, 1942; Stoddart and Fosberg, 1981) and petrography (Ginsburg, 1979). The outer island group (unnamed) nearest Key West and the Marquesas Keys located 29 km [18 mi] west of Key West, have calcareous sand beaches averaging 7.5 m [25 ft] in width (Clark, 1990). Beach sediments are comprised of calcareous skeletal fragments of green algae and oolitic sand. Net longshore sediment transport directions vary according to the beach alignment and exposure to wave activity. While shoreline stability is apparent in most areas during the 50 years since Davis conducted his study, significant beach losses have occurred due to the "quiet invasion" of mangroves (Clark, 1990). Although the length of the outer island beaches nearest Key West is over 4.2 km [2.6 mi], these front on the Straits of Florida. The northern shores of these islands appear to be stable mangrove shorelines. The cumulative length of the beaches of the Marquesas Keys is nearly 7.2 km [4.5 mi]. Long Beach Key, with over 4 km [2.5 mi] of continuous Gulf beach front is the longest and largest of all the islands west of Key West. Beach sediments are predominantly green algae fragments, a material which is readily produced in the adjacent waters. The dune ridge is stabilized by one of the densest communities of sea oats found along Florida's beaches. The most remote beaches of Florida are those of the Dry Tortugas or Tortugas Keys, which are located about 105 km [65 mi] west of Key West. All 6 islands of this group have beaches which cumulatively measure 7.2 km [4.5 mi] and are comprised largely of coral fragments as well as green algae. The nearly 3.2 km [2 mi] of beach on Loggerhead Key (the furthest west of all the Tortugas Keys) characterizes perhaps the highest wave energy conditions south of Cape Romano. The steeply sloping beaches of Loggerhead Key and Sand Key are fronted by a developing beachrock of indurated calcareous sand which Ginsburg (1979) describes as the only occurrence of marine beachrock in the continental United States. Examination of the beachrock reveals precipitated aragonite cement filling interstices between individual sediment particles. Beach processes of the Dry Tortugas are generally unresearched and in need of further study to determine erosion/accretion patterns and longshore transport processes.

HISTORICAL SHORELINE CHANGE DATA

Determination of long-term coastal behavior to be pursued and applied in regulating coastal excavation and construction activities in Florida became a mandate of the Florida State Legislature pursuant to the Growth Management Act of 1985. Adopted provisions are set forth in an amendment to the **Beach and Shore Preservation Act**, Section 161.053, subsection (6) of the **Florida Statutes**. Pursuant to requirements of this law, methodology for procuring and analyzing data, interpreting and accepting results, and their application are formalized by rule published in Chapter 16B-33 of the **Florida Administrative Code**. Space limitations, here, precludes inclusion of these provisions, and to paraphrase would not be appropriate. However, additional documentation is available. Considerations for adoption of the rule are outlined by Balsillie and Moore (1985); ensuing history and results of adoption are chronicled by Balsillie (1985b); more detailed technical issues were as directed by rule to be addressed and published in Division of Beaches and Shores Technical and Design Memoranda or other documents (e.g., Balsillie, in manuscript) deemed acceptable.

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