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Holocene evolution of Apalachicola Bay, Florida

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Abstract A program of geophysical mapping and vibra-coring was conducted to better understand the geologic evolution of Apalachicola Bay. Analyses of the geophysical data and sediment cores along with age control provided by 34 AMS ^{14}C dates on marine shells and wood reveal the following history. As sea level rose in the early Holocene, fluvial deposits filled the Apalachicola River paleochannel, which extended southward under the central part of the bay and seaward across the continental shelf. Sediments to either side of the paleochannel contain abundant wood fragments, with dates documenting that those areas were forested at 8,000 ^{14}C years B.P. As sea level continued to rise, spits formed of headland prodelta deposits. Between ~6,400 and ~2,500 ^{14}C years B.P., an Apalachicola prodelta prograded and receded several times across the inner shelf that underlies the western part of the bay. An eastern deltaic lobe was active for a shorter time, between ~5,800 and 5,100 ^{14}C years B.P. Estuarine benthic foraminiferal assemblages occurred in the western bay as early as 6,400 ^{14}C years B.P., and indicate that there was some physical barrier to open-ocean circulation and shelf species established by that time. It is considered that shoals formed in the region of the present barrier islands as the rising sea flooded an interstream divide. Estuarine conditions were established very early in the post-glacial flooding of the bay.

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Introduction

The Apalachicola River, located on the mid-Florida panhandle, is the largest river in Florida. The Apalachicola, Chattahoochee, and Flint river system originates in the highlands of Georgia, and is the principal contributor of clastic sediment to the eastern Gulf of Mexico (Doyle and Sparks 1980). At the river's mouth, an active delta prograde into Apalachicola Bay at an average rate of 2.2 m per year (Donoghue 1993). The estuary is approximately 65 km long, 2–12 km wide, and is shielded from the open Gulf by a well-developed, nearly continuous chain of three barrier islands. The three islands, St. George, Little St. George, and St. Vincent, shelter four bays, St. George Sound, East Bay, Apalachicola Bay, and St. Vincent Sound (Fig. 1). Within the bay, water depths range between 1 and 16 m, with an average of ~3 m water depth (mwd).

Analysis of well borings shows that Holocene clastic sediments of the Apalachicola Bay overlie heavily dissected Pliocene and Pleistocene surfaces (Schnable 1966; Schnable and Goodell 1968). Seismic surveys demonstrate that the Apalachicola River incised paleovalleys across the continental shelf during Pleistocene glacial sea-level low-stands (Donoghue 1992, 1993; McKeown et al. 2004). Incised channels occur from 5 to 40 m below sea level (mbsl), and provide evidence of multiple transgressive and regressive cycles during the Pleistocene (Donoghue 1992, 1993). During the last sea-level transgression, the incised valleys were filled by fluvial, then estuarine, deposits, which spread across much of the bay during the late Holocene (Schnable and Goodell 1968).

The shape of the Apalachicola Bay region itself prior to flooding during the late Holocene can be reconstructed from available well and seismic data. Measurements of depth to the Pleistocene surface were acquired during
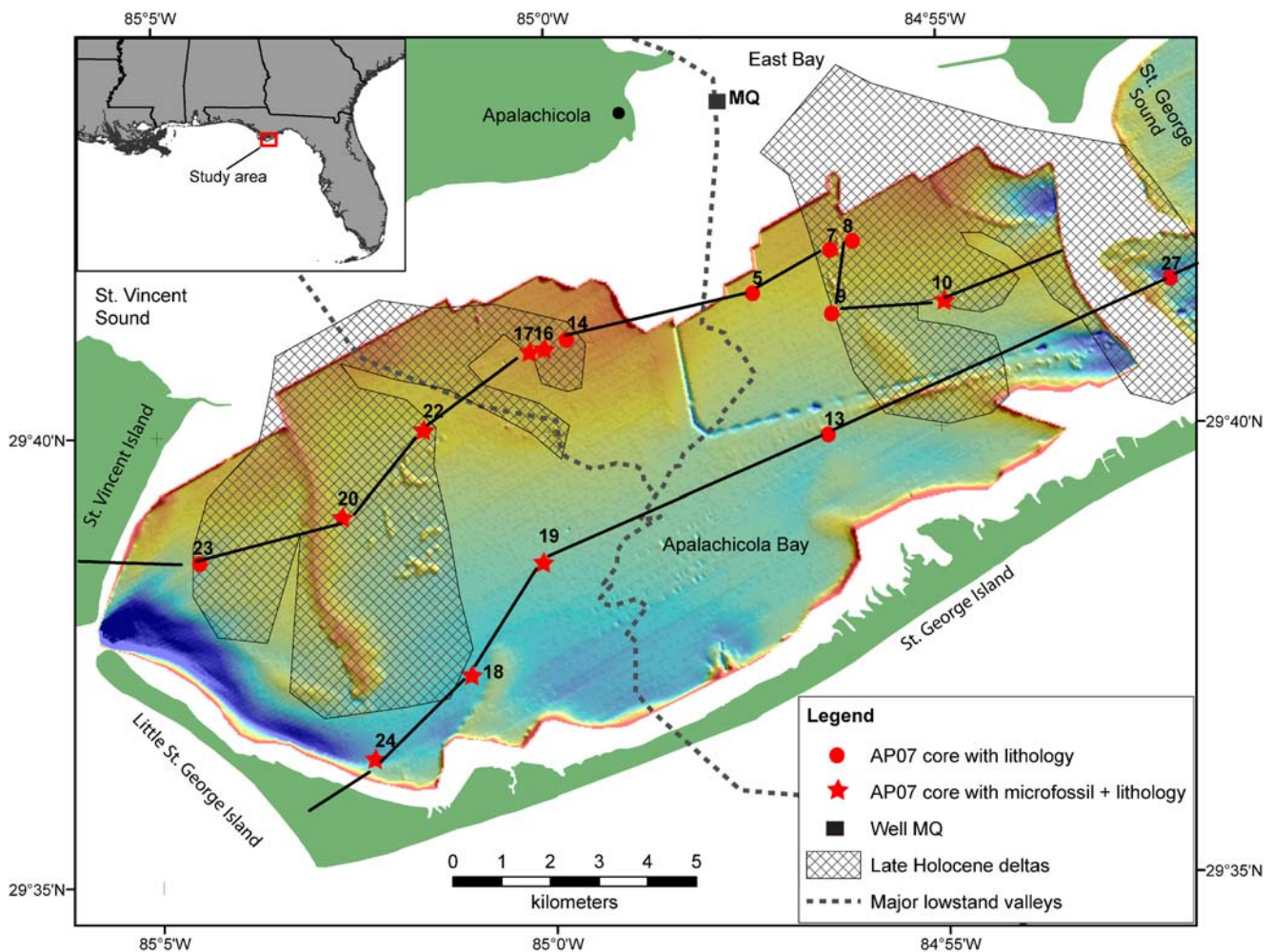
Fig. 1 Locations of vibracores in Apalachicola Bay, Florida, used in this study. The paleoenvironmental interpretation of the eight cores (*red stars*) is shown in Fig. 2. A stratigraphic correlation of all 16 cores is shown in the northern and southern transects of Fig. 3. The location of the lowstand valley (*dashed line*) is based on the seismic-survey work for this study and Donoghue (1993). The *hatched pattern* indicates the extent and distribution of late Holocene sandy deltaic deposits

bridge construction across the bay (Florida Department of Transportation 1959, 1979, 1999; Schnable 1966), and were extrapolated across the bay on seismic profiles (Donoghue 1992, 1993). The depths to Pleistocene are ~6 to 9 mbsl under central St. George Island, ~9 to 14 mbsl farther north in Apalachicola Bay, and ~11 to 22 mbsl in East Bay, which include paleovalley depths (Florida Department of Transportation 1959, 1979, 1999; Schnable 1966). Twichell et al. (2007) suggest that the Pleistocene surface is 6–8 mbsl throughout most of the bay away from the paleovalleys. This depth range agrees with coring by Otvos (1985) that places the Pleistocene surface at ~7 mbsl on St. George, and at ~18 mbsl immediately behind southern St. George Island at a site along the edge of the paleovalley. Basal Holocene sediments in the bay are documented by a 9,950 ^{14}C years B.P. radiocarbon date at 22 mbsl in a paleochannel (Schnable 1966).

Previous studies indicate that estuarine conditions in Apalachicola Bay began after the formation of the offshore barrier islands 4,500 to 3,000 years B.P. (Stapor 1973, 1975; Donoghue and White 1995; Forrest 2007; López and Rink 2008). Timing of establishment of the barrier islands and estuarine conditions is of interest because oysters thrive in the shallow protected water of the present Apalachicola Bay. The bay is the site of the largest oyster fishery in Florida (Whitfield and Beaumariage 1977). To understand the geologic evolution of Apalachicola Bay better, as it became linked to the oyster fishery, a program of geophysical mapping was followed by sedimentological and microfaunal analyses of vibracores.

Benthic foraminifers in the Gulf of Mexico have been well studied. Culver and Buzas (1983) summarized the large-scale species distributions reported in earlier works (e.g., Phleger and Parker 1951; Bandy 1954; Parker 1954). Applicable smaller-scale species distributions are discussed

in Phleger (1960), Otvos (1985), and Osterman (2003). The shallowest marine environments consist of low-diversity assemblages of agglutinated foraminifera along with *Ammonia* and *Elphidium*. As salinity increases, so do diversity and the percentage of calcareous species. Specifically, marginal-marine assemblages consist of 100% agglutinated species, whereas in brackish, shallow-water, lagoonal, and estuarine environments the foraminiferal assemblages consist of progressively more calcareous genera, including *Ammonia*, *Elphidium*, and *Quinqueloculina*, and fewer agglutinated species. The inner-shelf environment is characterized by increasingly diverse assemblages of additional species of the above genera, along with *Hanzawaia*, *Haynesina*, *Protononion*, and various Miliolaceans. Outer-shelf assemblages are most diverse and include all of the above, in addition to *Buccella*, *Bulimina*, *Brizalina*, and *Cibicides*.

Methods

Geophysical survey and coring

A detailed geophysical mapping effort was conducted in 2005 and 2006 (Twichell et al. 2007). Initial analyses of the high-resolution seismic profiles were used to design a vibracoring program for the summer of 2007. Cores were collected at 24 sites in the Apalachicola Bay and St. George Sound part of the estuary, using a Rossfelder electric vibracorer with a 6.1-m aluminum barrel deployed from the U.S. Geological Survey (USGS) R/V *G.K. Gilbert*. Core

sites included in this study are shown on Fig. 1 and listed in Table 1. The cores were split, described visually, and selected cores were sampled for radiocarbon dating, textural, and faunal analysis.

Dating

Chronology for the cores is provided by 34 AMS ^{14}C dates (Table 2). Wood and shell samples were converted to graphite targets at the USGS in Reston, VA. The AMS ^{14}C ages were determined at the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory in Livermore, CA. Quoted ages are in radiocarbon years (B.P.) using the standard Libby half-life of 5,568 years. The ^{14}C dates on marine shells (Table 2) do not include a reservoir correction.

Foraminifers

Microfossils were examined in 98 samples in eight vibracores. Sediments were processed without additional drying. Sediment was placed in a beaker containing water with a small amount of 5% Calgon solution, and agitated for less than 60 min. Fines were removed by washing the samples over a 63-µm sieve, and the larger residue was placed in a low-temperature oven to dry (<60°C). The dried fraction was sieved at 125 µm, and split as necessary using a microsplitter to obtain approximately 200±100 specimens. Foraminifers were picked from the sample, placed on a glued 60-square micropalentological slide, sorted, and

Table 1 Location of cores

Core	Latitude (N)	Longitude (W)	Water depth (m)	Core length (cm)	Location
AP07-05	29°41.514′	84°57.325′	2.9	460	Paleo-Apalachicola channel
AP07-07	29°41.972′	84°56.373′	2.7	507	Norman's Bar North
AP07-08	29°41.962′	84°56.372′	2.7	542	Norman's Bar North
AP07-09	29°40.993′	84°55.874′	2.7	533	Norman's Bar South
AP07-10	29°41.363′	84°54.970′	3.0	542	East of Norman's Bar
AP07-13	29°39.921′	84°56.386′	3.5	521	Shoreward of Cedar Point
AP07-14	29°41.043′	84°59.735′	2.2	528	Sugar Lumps Bar
AP07-16	29°40.871′	85°00.076′	2.0	472	Sugar Lumps Bar
AP07-17	29°40.872′	85°00.170′	2.2	480	Sugar Lumps Bar
AP07-18	29°40.873′	85°00.935′	3.7	427	Higgins Shoal
AP07-19	29°40.874′	85°00.036′	3.5	509	Edge of paleochannel
AP07-20	29°40.875′	85°02.437′	3.0	558	St. Vincent Bar
AP07-22	29°40.876′	85°01.491′	2.7	513	West Lumps Bar
AP07-23	29°40.877′	85°04.445′	3.2	518	Near St. Vincent Island
AP07-24	29°40.878′	85°02.170′	3.7	544	Back of Little St. George Island
AP07-27	29°40.879′	84°52.075′	3.5	467	East side of Hotel Bar

Table 2 Radiocarbon dates (*shells* date is on more than one valve, *shell* date is on a single valve)

	Core and depth	Material	δ^{13}C	^{14}C Age	±
1	APP05 177–178 cm	Wood	−25	2,940	35
2	APP05 285–287 cm	Shells	0	5,495	45
3	APP10 175–180 cm	Shell	0	5,125	35
4	APP10 486 cm	Wood	−25	6,910	35
5	APP10 502 cm	Wood	−25	7,020	35
6	APP16 94–96 cm	Shell	0	1,465	35
7	APP16 110 cm	Shells	0	1,515	45
8	APP16 420 cm	Shells	0	40,470	1,020
9	APP16 464–465 cm	Shell	0	54,200	2,800
10	APP17 112 cm	Shell	0	2,395	35
11	APP17 460 cm	Shell	0	43,070	720
12	APP18b 130 cm	Shells	0	1,550	35
13	APP18b 150 cm	Shell	0	2,990	30
14	APP18b 168–170 cm	Shells	0	3,060	35
15	APP18b 260 cm	Shell	0	5,530	35
16	APP18b 268 cm	Shells	0	5,165	35
17	APP19 120 cm	Shells	0	1,965	35
18	APP19 403 cm	Shells	0	6,350	45
19	APP20 185 cm	Shells	0	4,110	35
20	APP20 547–557 cm	Wood	−25	47,000	1,200
21	APP22 71–73 cm	Shell	0	1,260	35
22	APP22 73–75 cm	Shell	0	900	30
23	APP22 260 cm	Shells	0	3,760	35
24	APP22 487 cm	Wood	−25	8,325	35
25	APP23 314 cm	Shells	0	6,035	30
26	APP24 52–54 cm	Shell	0	2,575	30
27	APP24 53–54 cm	Shells	0	2,950	35
28	APP24 246 cm	Shell	0	2,565	40
29	APP24 266 cm	Shells	0	2,840	40
30	APP24 289–293 cm	Shells	0	4,875	35
31	APP24 322–327 cm	Shells	0	3,420	35
32	APP24 325–327 cm	Shells	0	5,005	45
33	APP24 335–336 cm	Shell	0	5,380	30
34	APP24 417 cm	Shells	0	6,460	35

identified using standard literature. Foraminiferal census data are reported elsewhere (Twichell et al. 2009).

Results

Biofacies analysis of eight cores

The benthic foraminifer assemblages along with characteristics of associated sediments were used to identify six depositional environments (Table 3) in eight cores from Apalachicola Bay. General sediment lithology and distri-

bution of the six benthic biofacies are shown in Fig. 2. The six environments are normal marine, estuarine, marginal marine, deltaic, terrestrial, and barrier-island washover. Salinity of the normal-marine environment is estimated to be 33–37‰ with water depths of 3–30 m, whereas the estuarine and marginal-marine environments represent gradationally lower salinities and shallower water depths.

A normal-marine environment is represented by predominately sandy sediments with a moderately diverse (Shannon-Wiener diversity index value H′>2.2) assemblage containing Miliolaceans (avg. of 27%) and epiphytic foraminifers (avg. of 21%; Twichell et al. 2009). Epiphytic species including *Rosalina floridana* and *Rosalina floridensis* live attached to sea grasses (Bock 1969). Therefore, these sediments indicate quiet, shallow water (~3–30 mwd)

Table 3 Foraminiferal biofacies

| Core	Number of samples	Number of species	Diversity (H′)
Normal-marine			
AP07-16	3	12–23	2.2–2.5
AP07-17	3	19–27	2.4–2.6
Estuarine			
AP07-10	5	7–12	1.4–2.0
AP07-16	4	6–8	1.3–1.7
AP07-17	11	6–10	1.1–1.9
AP07-18	11	9–16	1.6–2.2
AP07-19	7	7–12	1.5–2.0
AP07-20	6	9–13	1.4–1.7
AP07-22	6	5–9	1.3–1.8
AP07-24	15	6–11	1.6–1.9
Deltaic			
AP07-10	4	0–8	0–1.5
AP07-16	1	8	1.6
AP07-17	3	0	0
AP07-18	1	0	0
AP07-20	1	2	0.4
AP07-22	2	0	0
AP07-24	1	7	1.56
Marginal-marine			
AP07-10	2	1	–
Terrestrial			
AP07-10	2	0	0
AP07-20	2	0	0
AP07-22	1	0	0
AP07-24	3	0	0
Overwash			
AP07-18	3	7–8	1.7–1.8
AP07-24	1	11	1.76

$H' = -\sum_{i=1}^{S} p_i \ln p_i$
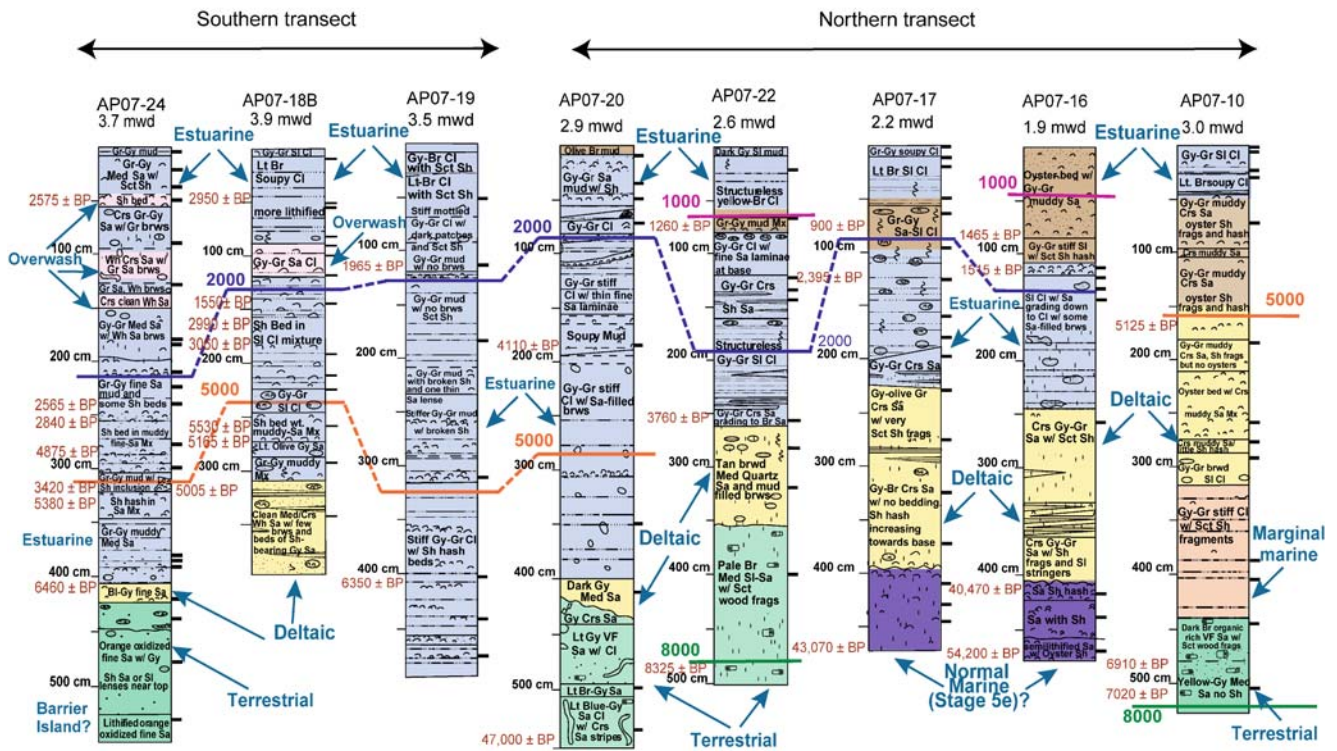
Fig. 2 Stratigraphic correlation of eight vibracores based on core-lithology descriptions and microfossil analysis. Microfossil analysis has defined six biofacies (terrestrial, normal marine, estuarine, marginal marine, deltaic, and overwash). Core locations are found in Fig. 1. *Bold black bars* at the right side of core columns mark the locations of the microfossil samples. Uncorrected radiocarbon dates are shown in *purple*. *Sa* Sand, *Sl* silt, *Cl* clay, *Bl* blue, *Br* brown, *Gr* green, *Gy* gray, *Wh* white, *Lt* light, *Med* medium, *Crs* coarse, *Mx* matrix, *Sh* shell, *Sct* scattered, *Brws* burrows, *w/* with, *VF* very fine, *frag* fragments

with a sandy bottom, reduced turbidity, and the presence of sea grass. Salinity is interpreted to be close to normal marine, with a location seaward of barrier islands. Infinite radiocarbon dates from shells in this facies, found at the bottom of cores AP07-16 and 17, place the age of this highstand deposit at possibly the last interglacial.

Silty and sandy muds containing a lower-diversity (H′~1.7) benthic foraminifer assemblage of euryhaline taxa characterize the estuarine facies. The estuarine assemblage is dominated (50–90%) by the three calcareous species *Ammonia parkensoniana*, *Ammonia veneta*, and *Elphidium excavatum*, which are indicative of shallow water depths, variable salinity, and fluvial influence. Because agglutinated species occur rarely in this facies, and are found mostly near the tops of several cores, their absence may be taphonomic. Shell beds are also common in the estuarine facies. The near-absence of shelf species, except as described in overwash sediments, indicates that there was restricted faunal and water exchange with the continental shelf. Additionally, the complete absence of epiphytic (sea grass-living) species implies that increased turbidity, rapid clastic sedimentation, or reduced salinity limited the occurrence of sea grass

during deposition of these sediments. The estuarine facies is found in every core analyzed for microfossils. An estuarine depositional environment interpreted as occurring in <10 mwd and behind a barrier shoal or island system is consistent with the data.

Marginal-marine sediments were sampled in only one core, AP07-10. These silty-clay sediments contain marine shells, diatoms, abundant organic material, plant fragments, and *Haplophragmoides* sp., a coarse-grained agglutinated foraminifer, indicating very low salinity and very shallow-water coastal deposition.

Burrowed, muddy sands containing few mollusks and rare, sometimes abraded, shallow-water foraminifera or barren samples are defined as deltaic sediments. The depositional environment is interpreted as occurring in the delta plain and delta-front environments, and in some cases deltaic sediments are interbedded with estuarine sediments. Deltaic sediments are found in the lower portions of every core, except AP07-19.

Terrestrial sediments are predominately sand with silt and clay, and contain scattered wood fragments but no shells. Some examples of this facies contain burrows and layers of

oxidized sediments. Wood-bearing terrestrial deposits with radiocarbon dates of 8,000–7,000 ^{14}C years B.P. were found in cores AP07-10 and 22, whereas the wood-bearing sediment in core AP07-20 yielded infinite dates, beyond the resolution of the radiocarbon dating method. The basal sediments of core AP07-24 consisted of well-oxidized orange sand with iron-cemented concretions, and no preserved terrestrial vegetation. However, this unit also contains partially dissolved and iron-stained benthic foraminifers that seem to identify several episodes of subaerial exposure.

Evidence of presumed barrier-island overwash is found in beds of white non-fossiliferous sand or thin sandy beds with rare numbers of transported shelf species, including *Hanzawaia*, and *Cibicides*. Both types of units are present within the estuarine muds in cores AP07-18 and 24, the two cores located closest to the barrier islands. Two radiocarbon dates on one sandy shell bed in AP07-24 (51 cm, Table 2) indicate reworked shells, which may provide evidence for a paleotempestite.

Stratigraphic analysis of 16 cores

The biofacies analyses shown on Fig. 2 were combined with basic lithologic descriptions of other cores from the bay and the high-resolution seismic data to construct two stratigraphic cross sections across the northern and southern portions of the bay (Fig. 3). The northern transect crosses two paleovalleys that converge into a single valley at the southern transect (Fig. 1). These valleys were identified on

the seismic profiles, but were too deep to be sampled by our cores. One deep boring in the axis of the paleovalley collected at site MQ (Fig. 1) penetrated basal sandy bay-head delta deposits overlain by a fining-upward sequence (Schnable 1966). Only in the uppermost 3 m of the boring did the sand content increase again.

The early Holocene deposits that fill the paleovalleys nearly to their rims are too deep to be sampled by our cores as well. Coring could reach only the shallow interfluves adjacent to the valleys, where medium-to-coarse sands with shells (AP07-16, and 17) or wood fragments (AP07-10, 14, 20, 22, 23, and 27) were recovered. The clean white-to-orange sand at the base of core AP07-24 is interpreted to be barrier-island or shoal deposits because of its non-fossiliferous nature, oxidation of sediment, and the absence of mud and wood (Fig. 2).

Our cores show that once the paleovalleys filled, sediment spread laterally across the entire bay (Fig. 3). The deposits that initially cover the fine-grained paleovalley fill and coarser-grained interfluve deposits are a mix of mud, muddy sand, and clean sand. The estuarine nature of the fauna in the fine-grained sediments (AP07-193 05, 07, 08, 09, 13, and 19) indicates that sheltered estuarine conditions began immediately once the bay began to flood. The widespread extent of the estuarine deposits suggests that a barrier-island or offshore shoal system was in place across the entire southern edge of the bay early in the history of sedimentation in the bay. Some of the sandy beds found interbedded with the estuarine sediments in the upper sections of cores AP07-18 and 24 may be barrier-island overwash deposits.
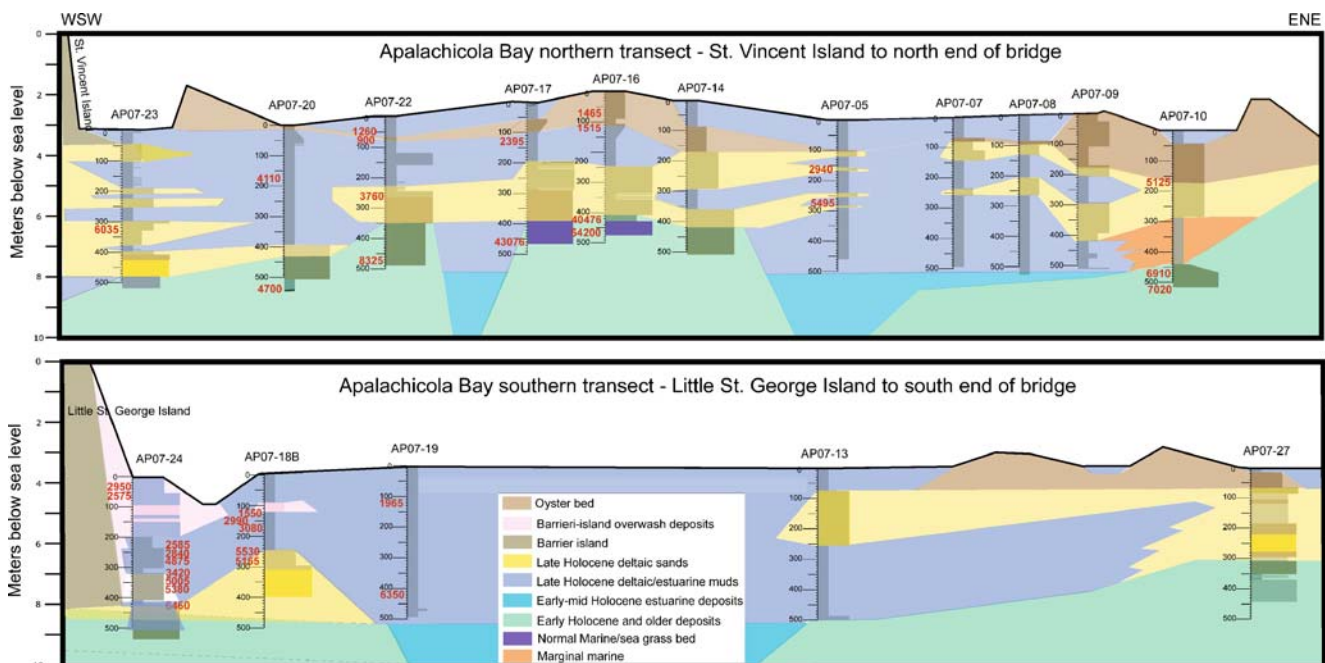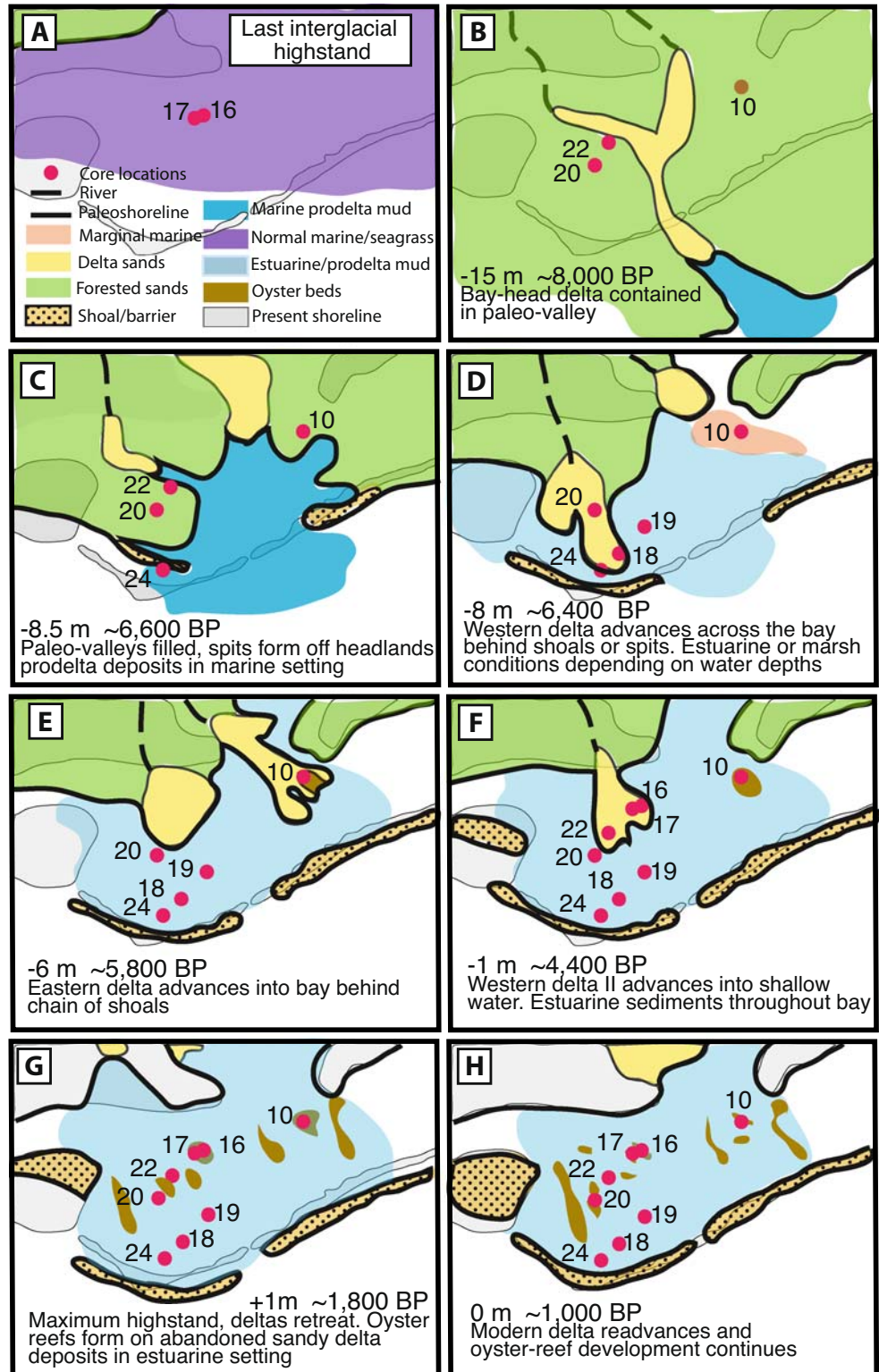

Fig. 3 Cross section showing the stratigraphic correlation based on high-resolution seismic profiles, core descriptions, grain-size analyses, and radiocarbon dating. Locations of the 16 cores on the northern and southern transects are shown in Fig. 1. Uncorrected radiocarbon dates are shown in *red*

Other thick intervals of muddy sand devoid of marine or estuarine fauna are observed in many of the cores (Fig. 3), and are interpreted as the coarse components of delta systems. The top of the sandy-delta deposits coincides with high-amplitude reflections on seismic profiles, which were used to map the geographic extent of the deltaic deposits (Fig. 1). As the deltas advanced southward into the bay, behind the emerging barrier-island-shoal system, deltaic sands and prodelta mud accumulated in this estuarine setting (Fig. 3). Many of the cores show that once the

Fig. 4 **a–h** History of the Apalachicola Bay based on the results of this study focusing on the eight cores used for microfossil analysis. Figure part **a** contains the key for sedimentary environments recorded in the vibracores

A Last interglacial highstand

• Core locations
— River
— Paleoshoreline
Marginal marine
Delta sands
Forested sands
Shoal/barrier
Marine prodelta mud
Normal marine/seagrass
Estuarine/prodelta mud
Oyster beds
Present shoreline

B -15 m ~8,000 BP
Bay-head delta contained in paleo-valley

C -8.5 m ~6,600 BP
Paleo-valleys filled, spits form off headlands prodelta deposits in marine setting

D -8 m ~6,400 BP
Western delta advances across the bay behind shoals or spits. Estuarine or marsh conditions depending on water depths

E -6 m ~5,800 BP
Eastern delta advances into bay behind chain of shoals

F -1 m ~4,400 BP
Western delta II advances into shallow water. Estuarine sediments throughout bay

G +1m ~1,800 BP
Maximum highstand, deltas retreat. Oyster reefs form on abandoned sandy delta deposits in estuarine setting

H 0 m ~1,000 BP
Modern delta readvances and oyster-reef development continues

deltas were abandoned, the sandy parts were colonized by oysters (Fig. 3). The oyster beds have subsequently decreased in areal extent, due to burial by the continued influx of fine-grained sediment to the bay by the Apalachicola River.

Discussion

The combination of high-resolution seismic profiles and biofacies analyses with radiocarbon control enables the following reconstruction of the evolution of Apalachicola Bay (Fig. 4). Sea-level estimates are based on the history proposed by Balsillie and Donoghue (2004) for the Gulf of Mexico (Fig. 5). At the base of AP07-16 and 17, normal-marine conditions occur. These sediments, with infinite ^{14}C dates, are interpreted to represent a shelf environment that formed during the last interglacial highstand (Fig. 4a). The diverse fauna, which includes Miliolaceans and epiphytic (sea grass-living) forms, indicates a higher-than-present sea level with barrier islands absent or occurring landward of this location (Donoghue 1992). This was a quiet, sandy bottom with patches of sea grass. Following that highstand, sea level fell and the Apalachicola River incised paleovalleys that extended to the shelf edge (Donoghue 1993; McKeown et al. 2004).

During the sea-level lowstand, the exposed continental shelf was a terrestrial, vegetated coastal plain (Fig. 4b). Cores AP07-10, 20, and 22, to either side of the paleochannel where it crossed the present extent of Apalachicola Bay, contain abundant wood fragments with ^{14}C dates documenting forested areas at 8,000 ^{14}C years B.P. and earlier. As sea level rose following the last glacial maximum, fluvial deposits filled the Apalachicola River paleochannel, and bay-head deltas were deposited in the incised valleys off the mouth of the river (Fig. 4b).

As sea level rose to between 9 and 8 mbsl, coastal regions surrounding the paleovalleys were inundated, and the bay-head deltas continued to retreat landward (Fig. 4c). Preservation of wood-bearing sediments in cores AP07-10, 20, and 22 indicates bay inundation was not yet extensive. Core AP07-24, which is farther offshore, contains clean white and orange sand with no foraminifers, which may be possible evidence for subaerial exposure perhaps indicating the initial formation of a barrier spit (Figs. 2 and 3).

Once the sea level reached 8 mbsl, much of the present bay was flooded (Figs. 4d and 5). In core AP07-10, the encroaching shallow water deposited marginal-marine sediments containing agglutinated foraminifers and diatoms that overlie the wood-bearing sediments (Figs. 2 and 3). In the western part of the bay, deltaic sediments are found in cores AP07-18 and 20 (Figs. 2, 3 and 4d). In core AP07-24, a thin interval of deltaic sediment with a date of 6,460 ^{14}C years B.P. is overlain by estuarine sediment (Fig. 2). Fine-grained estuarine sediments are found throughout AP07-19, indicating that this site was outside the influence of the sandy component of the deltas.

As sea level continued to rise to 6 mbsl (Figs. 4e and 5), an eastern deltaic lobe advanced over older marginal-marine sediments in AP07-10. In the eastern core AP07-10, deltaic sediments with oyster shells continued to be deposited until shortly after ~5,125 ^{14}C years (Table 2). In the western bay, estuarine sedimentation occurred landward of the barrier islands in cores AP07-18, 19, 20, and 24.

Radiocarbon-dated shells in deltaic sediments, found in cores AP07-16, 17, and 22, provide evidence for continued development of the western delta that may be associated with the fall in sea level beginning at ~4,600 ^{14}C years B.P. (Balsillie and Donoghue 2004; Figs. 4f and 5). Radiocarbon-dated shells in estuarine sediments overlying the deltaic deposits indicate that progradation in the bay was ended ~2,500 ^{14}C years B.P. Estuarine conditions are found throughout the bay after that time, but oysters are limited to the sandy deposits in the eastern part of the bay (AP07-10).

The highest post-glacial sea level is reported (Balsillie and Donoghue 2004) to have occurred at ~1,800 ^{14}C years B.P.

Fig. 5 Gulf of Mexico sea-level curve from Balsillie and Donoghue (2004). *Boxes* labeled C–H correspond to the figure parts in Fig. 4. Episodes of possible delta formation (*yellow bars*) based on radiocarbon dates (*red stars*) in the cores are shown at the bottom. *Numbers* on stars refer to the dates in Table 2. Estuarine sedimentation is shown with a *blue bar*. Maximum and minimum dates for the events are shown with associated *arrows*. All ages are uncalibrated
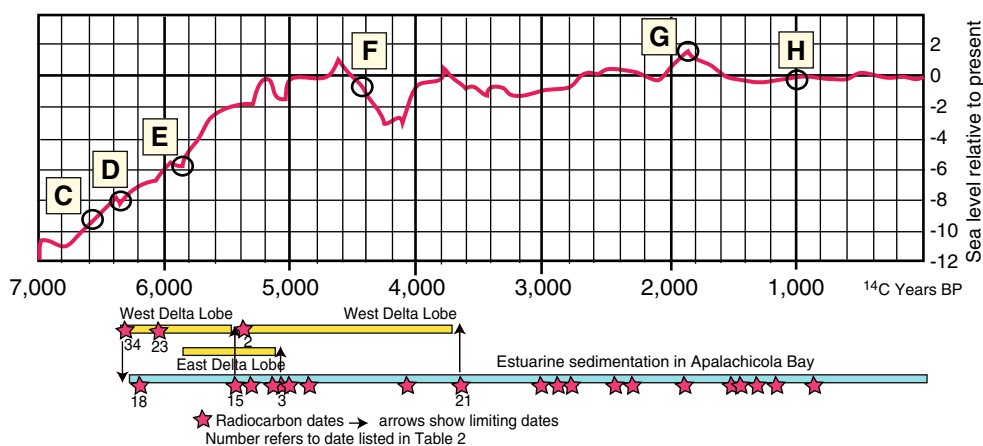
(Figs. 4g and 5). At this time estuarine sediments are found in every core, and oyster beds are found in their maximum occurrence throughout the bay.

Modern sea-level conditions are established at ~1,000 ^{14}C years B.P. (Figs. 4h and 5). Since then, the modern Apalachicola delta has been re-advancing into the bay, and the associated prodelta muds have blanketed some oyster beds and decreased their extent.

Timing and origin of the barrier islands

Radiocarbon dates indicate that the oldest beach strand on St. Vincent Island was fully formed by 4,500 ^{14}C years B.P. (Forrest 2007). However, two limiting radiocarbon dates from the AP cores indicate that shallow-water shoals may have been a feature restricting water circulation to the bay as early as 6,400 ^{14}C years B.P. (Table 2). A date of 6,350 ^{14}C years B.P. on shells from fine-grained sediment with estuarine fauna in AP07-19, and of 6,460 ^{14}C years B.P. on a thin bed of deltaic sediments in AP07-24 that is overlain by estuarine sediments provide evidence for the establishment of a fairly continuous offshore shoal that restricted the influx of normal-marine species into Apalachicola Bay by ~6,400 ^{14}C years B.P.

The Apalachicola vibracore analyses indicate that both last interglacial (Fig. 4a) and exposed coastal-plain sediments (Fig. 4b) are predominately sand, and could have provided a sufficient quantity of sediments for the ultimate development of shoals and barrier islands. Culver et al. (2007) found that the position of the North Carolina Outer Banks barrier islands is related to a former topographic high. They propose that the initial formation of the Outer Banks occurred on the crest of a Pleistocene interstream divide as rising post-glacial sea level flooded the incised fluvial topography. Likewise, post-glacial marine transgression over the Apalachicola coastal-plain topographic highs could have led to the initial formation of shoals, and ultimately the barrier islands (Fig. 4c). The seismic and borehole measurements indicate that the Pleistocene surface on the Apalachicola shelf had considerable topography. Prior to the last marine transgression, topographic highs existed where parts of the barrier islands are found today (~6 to 9 mbsl), and topographic lows (~6 to 22 mbsl) occurred landward of the barrier islands (Florida Department of Transportation 1959, 1979, 1999; Schnable 1966; Otvos 1985). The timing of shoal formation is therefore indirectly inferred based on the establishment of estuarine conditions in Apalachicola Bay. The two limiting dates on estuarine sediments, >6,350 ^{14}C years B.P. in AP07-19 and <6,460 ^{14}C years B.P. in AP07-24, provide evidence that circulation was restricted in the bay as early as 6,400 ^{14}C years B.P. (Fig. 5).

Conclusions

This study indicates that development of estuarine conditions in Apalachicola Bay began in the early Holocene post-glacial transgression (~6,400 ^{14}C years B.P.). Delta progradation into the Apalachicola Bay was a long continual process from before 6,460 ^{14}C years B.P. to after 2,940 ^{14}C years B.P., when sea level was between 8 and 1 mbsl lower than present. The advance of the deltas into the bay introduced a sandy substrate that provided the requisite habitat for subsequent oyster colonization. Oyster reefs are present before 5,125 ^{14}C years B.P. in core AP07-10 in eastern Apalachicola Bay, and appear to have colonized the western bay after 2,400 ^{14}C years B.P. Oyster beds had the greatest geographic distribution between 1,500–2,400 ^{14}C years B.P. Since 1,500 ^{14}C years B.P., the distribution of oyster beds has been decreasing in Apalachicola Bay.

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Faunal list

Ammonia veneta (Schultze, 1854)

Ammonia parkinsoniana (d'Orbigny) = *Rosalina parkensoniana* d'Orbigny, 1939

Elphidium excavatum (Terquem) = *Polystomella excavata* Terquem, 1876

Rosalina floridana (Cushman) = *Discorbis floridanus* Cushman, 1922

Rosalina floridensis (Cushman) = *Discorbis bertheloti* var. *floridensis* Cushman, 1930