Marine Inundated Archaeological Sites and Paleofluvial Systems: Examples from a Karst-Controlled Continental Shelf Setting in Apalachee Bay, Northeastern Gulf of Mexico

Michael K. Faught*

Department of Anthropology, Florida State University, Tallahassee, Florida 32306; and Florida Museum of Natural History, Gainesville, Florida 32611

Joseph F. Donoghue

Department of Geology, Florida State University, Tallahassee, Florida 32306

Underwater geoarchaeological research in Apalachee Bay, in the northeastern Gulf of Mexico off northwest Florida, has enabled the reconstruction of portions of the karst-controlled paleodrainage system, the discovery of several inundated prehistoric archaeological sites, and the exposure of sediments accumulated during the drowning of the continental shelf. Diagnostic artifacts discovered at the sites included chipped stone tools and debitage indicating Paleoindian, Early Archaic, and Middle Archaic occupation. A geoarchaeological model using terrestrial analogs was used to locate and investigate inundated sites. Methods employed include seismic profiling, vibracoring, diver tow surveys, diver collection transects, and induction dredge excavations. We document evidence for sea-level rise, related environmental succession and site formation processes for indundated prehistoric sites in the Apalachee Bay region from approximately 8000 to 6000 yr B.P.

INTRODUCTION

The discovery, analysis and interpretation of prehistoric archaeological sites submerged by sea-level rise depend on principles of geoarchaeology. Most examples of these kinds of sites have been located by chance, primarily in nearshore settings. Underwater archaeology focused on marine inundated prehistoric sites is an emerging subdiscipline that aims to reconstruct the inundated portion of past settlement patterns, subsistence activities, and cultural history before and during the process of submergence, as well as to describe the site formation processes afterwards (Faught, 1996).

Our understanding of late Pleistocene and early Holocene settlement patterns, subsistence activities, and migration routes is incomplete because post-

* Present address: Bureau of Archaeological Resources, Florida Department of State, Tallahassee, FL 32399-0250.

Geoarchaeology: An International Journal, Vol. 12, No. 5, 417–458 (1997)
 CCC 0883-6353/97/050417-42

glacial sea-level rise has submerged the world's continental shelves (Bailey and Parkington, 1988; Dixon, 1989; Fladmark, 1979; Masters and Flemming, 1983; Perlman, 1980; Widmer, 1988). As a result, systematic methods for finding and sampling archaeological sites offshore need to be developed and put into practice (Faught, 1996; Flemming, 1983; Gagliano et al., 1982; Kraft et al., 1983; Murphy, 1990; Pearson et al., 1986; Stright, 1986a, 1986b, 1990).

One specific research problem that can benefit from underwater geoarchaeological investigation is the fluted point Paleoindian colonization of the southeastern United States. Underwater research in this region is necessary because Paleoindian and Early Archaic sites can be expected to continue out onto the continental shelves (Emery and Edwards, 1966; Edwards and Emory, 1977) and because there is a current sparsity of radiocarbon dates for early Paleoindian occupation of the region (Stanford, 1991). These facts act as stumbling blocks for modeling the pattern and process of the fluted point Paleoindian colonization of all of North America (Anderson, 1991; Bonnichsen, 1991; Faught et al., 1994; Faught, 1996; Kelly and Todd, 1988; Stanford, 1991). Due to the fact that a substantial portion of the landmass—the continental shelf—of the Southeastern region was inundated by postglacial sea-level rise, it makes sense to look offshore in this region for more sites and for protected stratigraphic settings for radiocarbon dating.

Paleoindian and Early Archaic diagnostic artifacts are relatively abundant in northwestern Florida, especially when compared at a continental scale, and they indicate a specific region exploited by Paleoindians and their immediate progeny (Figure 1) (Faught et al., 1994; Faught, 1996). Most of these sites are drowned former freshwater locales (Dunbar, 1991). The karst-controlled Aucilla River (Figures 2 and 3), in particular, has produced several Paleoindian and early Archaic archaeological sites in freshwater inundated settings (Serbousek, 1983; Dunbar et al., 1988, 1989; Milanich, 1994; Purdy, 1991). It is hypothesized that these sites are found in karst features because with lower base levels and generally dryer conditions—as inferred from pollen data—during late Pleistocene time (Watts, 1983), specific aquifer-connected sinkholes were locations of faunal and lithic resources. Humans would have accessed resources at such locations. Subsequent sea-level-controlled water table rise and sedimentation inundated and buried the remains (Dunbar and Waller, 1983; Dunbar, 1991; Neill, 1964).

Scientific research was initiated in the Aucilla River in 1983 by the University of Florida (D. S. Webb) and the Bureau of Archaeological Research, Florida Department of State, Tallahassee (J. S. Dunbar). Focused on the discovery of *in situ,* freshwater-inundated Paleoindian and Early Archaic sites and extinct faunal remains, the Aucilla River Prehistory Project (ARPP), as it is now known, has undertaken several survey and excavation projects in and around the sinkholes of the karstic Aucilla drainage system (Dunbar et al., 1989, 1988; Richardson, 1988; Webb et al., 1984; Willis, 1988; Faught, 1996).

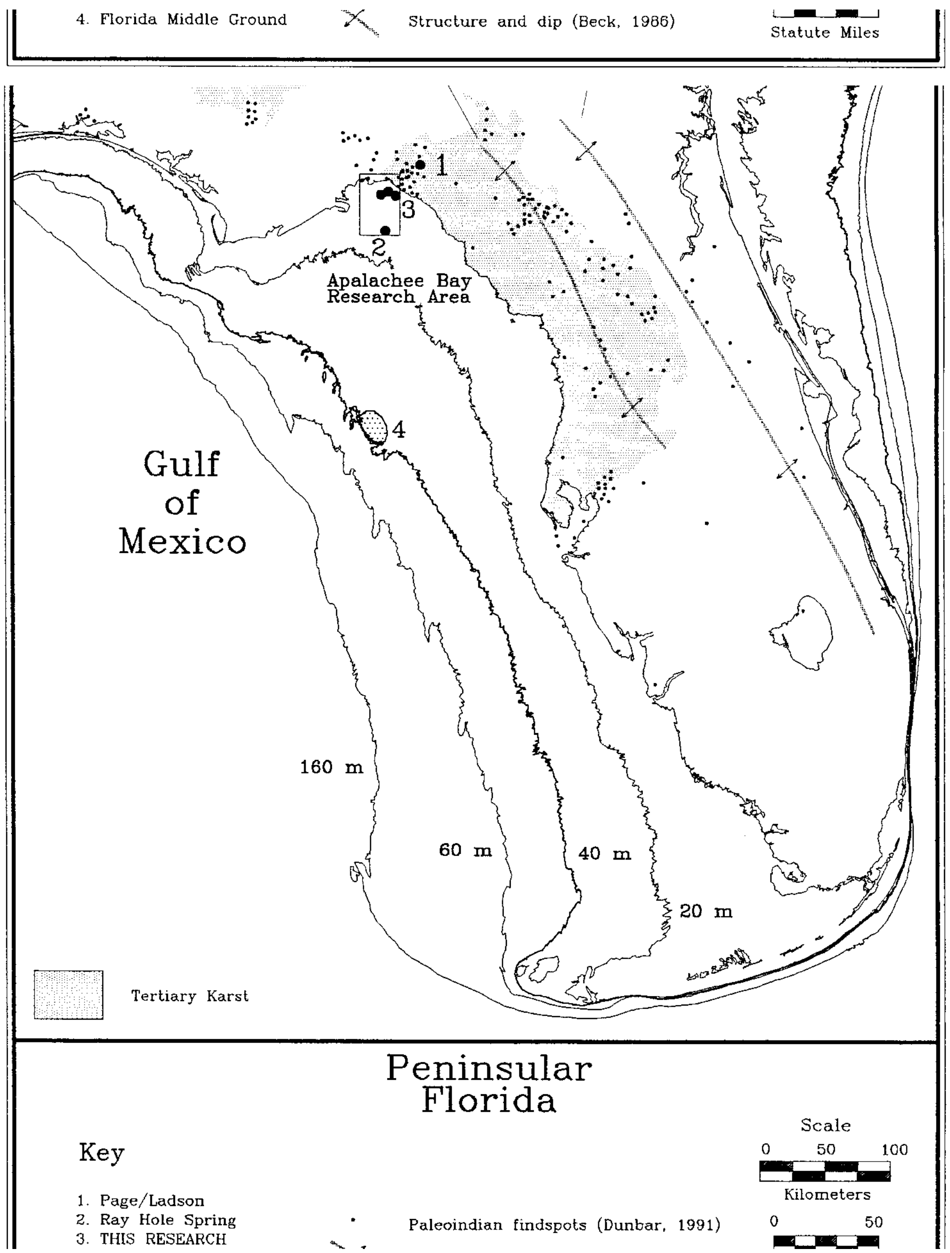

Figure 1. Peninsular Florida showing geologic structure, major karst areas and Paleoindian sites. Numbered locations are described in text. Research area is indicated by outline and shown in Figure 2. Continental shelf bathymetry in meters.

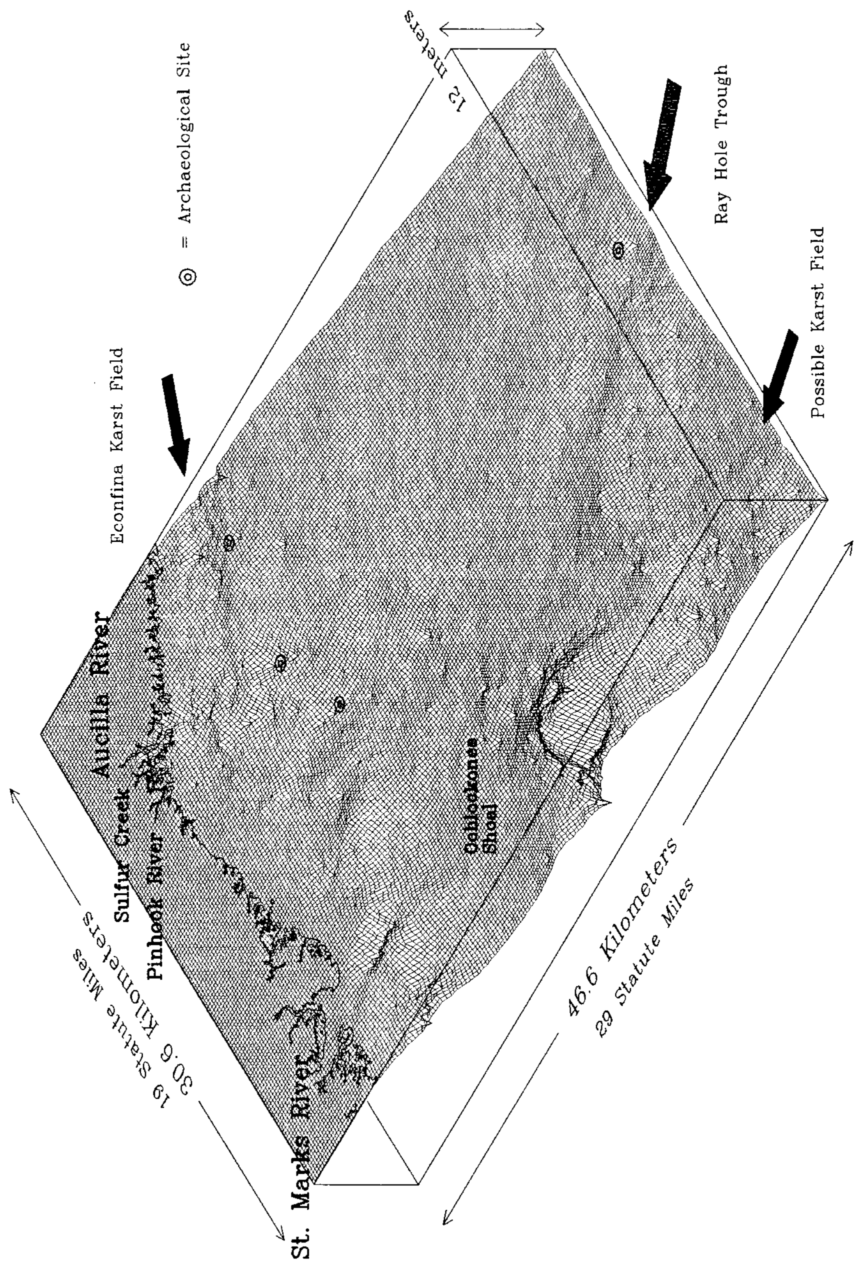

Figure 2. Topographic mesh diagram of the research area showing features described in text. North is to upper left. Location is outlined by rectangle in Figure 1.

Much ARPP attention has focused on the Page/Ladson Site (State of Florida site designation 8 Je 591), one of several sinkholes in a discontinuous segment of the Aucilla River. This site has produced abundant early diagnostic projectile points, chipped stone tools, and debitage in both primary and reworked stratigraphic contexts. Bones of extinct mammals are also abundant in this sinkhole and include mastodon, mammoth, horse, and sloth, among others. Some of these extinct faunal remains, and others from the Aucilla River, exhibit probable cut marks from butchering activities and other evidence of association with humans (Webb et al., 1984). Bolen/Big Sandy projectile points (Anderson and Hanson, 1988) and associated bifacial chipped-stone adzes have been found with abundant wood in primary contexts. Two radiocarbon dates from these contexts average 10,140 yr B.P. (Dunbar et al., 1988, 1989). The extinct faunal remains have stratigraphically associated radiocarbon dates, which cluster around 12,300 yr B.P. However, unequivocal *in situ* associations and radiocarbon control for earlier Paleoindian items remain elusive.

Due to the fact that the continental shelf in this region is a drowned continuation of extensive karst areas onshore (Figure 1), the potential for analogous discoveries offshore is great (CEI, 1977; Rupert and Spencer, 1988). For this reason, underwater geoarchaeological research was initiated in this region in 1986 by one of the authors (M.K.F.). The goal was to find archaeological sites offshore and, in particular, to locate a drowned sediment-filled analog of the sinkhole at the Page/Ladson Site onshore, and excavate for *in situ* stratigraphy and Paleoindian artifacts (Faught, 1996).

The discovery of marine inundated prehistoric archaeological sites in any particular region depends on the knowledge of local geomorphological settings of onshore archaeological sites, in order to find analogs of such settings offshore. Furthermore, the kinds of alterations which might affect the appearance and/or condition of these sites before, during and after marine transgression also need to be determined (Emery and Edwards, 1966; Edwards and Emory, 1977; Edwards and Merrill, 1977; Garrett, 1983; Gifford, 1990; Kraft, 1986; Johnson and Stright, 1992; Kraft et al., 1983; Pearson et al., 1989; Ruppe, 1980; Stright, 1986a, 1986b, 1990).

As stated at the outset, the goal of marine inundated prehistoric archaeology is to contribute to the reconstruction of past human settlement patterns, subsistence activities, cultural histories, and site formation processes, as they evolved on the continental shelf before, during and after submergence. To accomplish this, it is necessary to reconstruct the pattern of the submerged portions of the paleodrainage system and to identify other relevant geomorphologic features that existed during times of lower sea-level and then to determine the chronology and impact of the marine transgression. To this end, we inventory, describe, analyze, and interpet all geomorphologic features, stratigraphic records, and inundated sites that are encountered, regardless of age.

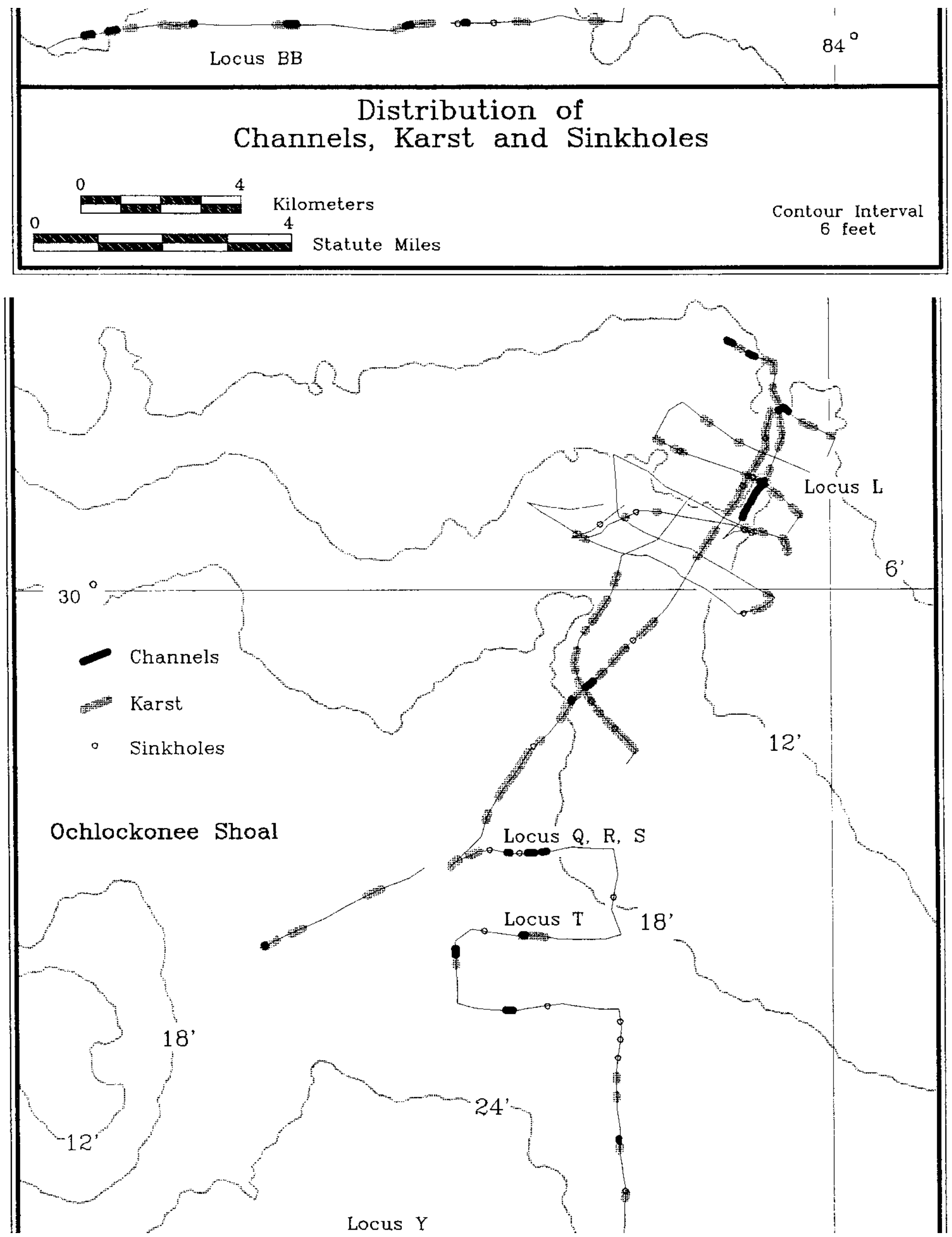

Figure 3. Distribution of channels, karst, and sinkholes in the research area, as determined from the subbottom profile records. Thin lines delineate some of the seismic tracklines. Labeled locations are described in text. Bathymetric contours in feet, from NOAA charts. Location is outlined by rectangle in Figure 1.

STUDY AREA

Apalachee Bay Region

Apalachee Bay (Figure 1) is a large embayment in the northeastern corner of the Gulf of Mexico. It comprises the drowned lower reaches of the Ochlockonee, St. Marks, Aucilla, and Econfina rivers, among others (Figures 2 and 3). (The modern Ochlockonee River mouth lies a few kilometers west of the Ochlockonee Shoal shown in Figures 2 and 3). The Ochlockonee and St. Marks rivers share characteristics of both karst- and alluvially-controlled drainage systems by exhibiting karstic solution and collapse features along their courses, but also by delivering fluvial sediments to the continental shelf offshore. The sand transported by these drainage systems covers the northern portions of the embayment, outside the current study area (Doyle and Sparks, 1980).

The Aucilla and Econfina rivers are, on the other hand, fully karst-controlled. The shelf offshore from these drainage systems is a low energy and sediment-starved former karst plain (CEI, 1977; Rupert and Spencer, 1988). The modern terrestrial vegetation is a species-rich forest with abundant pine (*Pinus*), oak (*Quercus*), and cypress (*Taxodium*). This thick forest cover gives way to a marsh grass coastal zone approximately 1 mile wide bordering the Gulf marine environment. Oyster (*Crassostrea rhizophorae*) bioherms are frequent at the mouths of the rivers and associated tidal creeks; sea grass beds with burrowing scallops (*Pecten* sp.) are frequent in the nearshore environment. Exposed or thinly covered outcrops of Tertiary limestone are common offshore, and karstic voids and joints of varying size occur within them. Sediment thickness is variable, depending on local bedrock morphology (Hutton et al., 1984). In buried channels and sinkholes, of course, sediment thickness can be considerably greater.

There are several reasons why this shelf embayment is an ideal location to prospect for inundated archaeological sites. First, there are high frequencies of Paleoindian and Early Archaic remains and archaeological sites onshore, indicating early Paleoindian presence and subsequent occupation through many generations. This fact allows for a wide range of potential site types in both submerged coastal and terrestrial settings (Dunbar and Waller, 1983; Dunbar, 1991; Faught, 1996; Faught et al., 1994; Milanich, 1994; Faught and Donoghue, 1994). Second, the local geology is of low relief, with karstic collapse and solution features common. Many sinkholes occur in linear clusters, forming discontinuous river channel segments, while others are isolated. Drowned sinkholes, indicating past sea-level low-stands, have been observed across the full width of the continental shelf. Scattered ledges and other outcrops of resistant limestone and secondary chert rise from the surrounding sandy shelf sediments, further indicating karstic dissolution of the underlying limestone bedrock (Bergantino, 1971; Bloom, 1983; CEI, 1977; Faught, 1996; Garrison, 1992; Jordan, 1952, 1954; Serbousek, 1988). Because the karst topography continues out onto the continental shelf and because most of the on-shore Paleoindian and Early Archaic archaeological materials are found in and around karst features, the possibility of discovering archaeological sites by searching around drowned offshore analogs is excellent (CEI, 1977; Gagliano et al., 1982; Dunbar, 1991; Faught, 1996).

Regional Karst Processes

A significant factor in favor of offshore archaeological site discovery in this area is the discontinuous nature of the karst drainage system, which conducts groundwater flow through complex underground connections (Beck, 1986). The major erosional process in the region is chemical dissolution, and the discontinuous nature of the system creates a "sieving" process for any fluvial sediments. As a consequence the streams are sediment-starved, and terrigenous sediment cover offshore is minimal—so minimal, in fact, as to allow sampling of some archaeological sites by hand fanning. Additionally, the low slope of the continental shelf and the relatively protected nature of Apalachee Bay create a mild and preserving marine environment, which may temper the disturbance of archaeological sites by transgressing seas and storm surge.

The geomorphologic significance of groundwater flow in this region can not be underestimated, especially in the present study area. Florida has 300 known springs, 27 of which are first-magnitude, that is, with a discharge rate exceeding 100 cfs (2.8 $m^3 s^{-1}$), far more than any other state (Rosenau et al., 1977). The outflow from these large springs totals more than 9600 cfs (272 $m^3 s^{-1}$). Total discharge from all of Florida's springs is estimated at 12,600 cfs (357 $m^3 s^{-1}$). The great majority of the first magnitude springs discharge directly or indirectly to the Gulf coast. The largest of these by far is Spring Creek Springs, discharging more than 2000 cfs (57 $m^3 s^{-1}$) directly into Apalachee Bay, just 11 km west of the St. Marks River mouth (Rosenau et al., 1977). By comparison, the average annual discharge of Florida's 20 major rivers is 70,123 cfs (1986 $m^3 s^{-1}$) (Fernald and Purdum, 1992). Groundwater discharge via terrestrial springs therefore contributes a significant fraction—approximately one-sixth—of the freshwater that runs off from the subaerial portion of the Florida platform and into the ocean.

Freshwater also discharges directly through the floor of the continental shelf and outer margin at places where coastal aquifers crop out at the sea bottom (Rosenau et al., 1977). This seepage is modern evidence of the processes which produced the now-buried karst features on the modern shelf during Pleistocene low-stands. Today, even the drowned and partly buried karst features on the shelf continue to be active. For example, Ray Hole Spring (location shown in Figure 2), a sinkhole identified as an early human site 40 km offshore in Apalachee Bay, was reported to be flowing when discovered in 1976 (Anuskiewicz et al., 1994; Rosenau et al., 1977). Partial infilling since that time has apparently shut off freshwater flow. Salinity profiles in the sinkhole show no present-day evidence of spring activity (Donoghue et al., 1995).

Estimating the magnitude of seepage through the floor of the continental shelf is complex. Few attempts have been made to quantify it. In a study of Great South Bay, New York, Bokuniewicz (1980) estimated that as much as 20% of the freshwater discharge to the bay was via seepage. A tracer study by Moore (1996) found that, along the South Carolina coast, the amount of groundwater seeping out of the bottom of the Atlantic shelf was equal to nearly half of the water discharged to the sea by rivers. A recent study in the northeastern Gulf of Mexico made direct measurements of seepage rates on the inner shelf immediately west of the study area, near Alligator Point, Florida. Cable et al. (in press) found that submarine seepage rates vary considerably, in part responding to precipitation levels. Using their midrange measured rates, however, we calculate that the inner shelf seafloor of Florida discharges freshwater at a rate of more than 64,000 cfs (1812 m^3 s^{-1}) nearly equal to the combined flow of Florida's 20 largest rivers.

Groundwater processes have been, and continue to be, the predominant factor in the evolution of the landscape in the Apalachee Bay region, just as it is on the adjacent coastal plain today. During Pleistocene low-stands, when more of the region was terrestrial, groundwater movement allowed development of springs, sinkholes, and caverns, providing habitat and sustenance for early humans. These same features tend to preserve and protect evidence for these activities, making the region especially important for both paleoenvironmental and archaeological research.

METHODS

Random Surveys

One procedure for locating archaeological sites offshore is to find submerged rock outcrops, test for the presence of chert resources, and, if present, search the nearby sediments for chipping debitage (Faught, 1988, 1989, 1990; Dunbar et al., 1992). In the study area chert outcrops were located by studying the NOAA Apalachee Bay navigational charts, by interviewing local divers and fishermen familiar with the area, and by towing SCUBA divers behind small boats. Eighteen sites were identified by this method. These included 15 "encounters" (fewer than 10 artifacts) and three sites that produced significant clusters of artifacts. These three sites are designated as the Fitch Site (8 Je 739), the J&J Hunt Site (8 Je 740), and the Econfina Channel site (8 Ta 139 (Figure 4).

Sampling was done by hand fanning 50 cm × 50 cm × 20 cm exposures at 5, 10, and/or 20 m intervals along collection transects. These transects radiated from LORAN-C controlled datum markers driven into joints in the bedrock or into the surrounding sediments. All artifacts encountered while hand

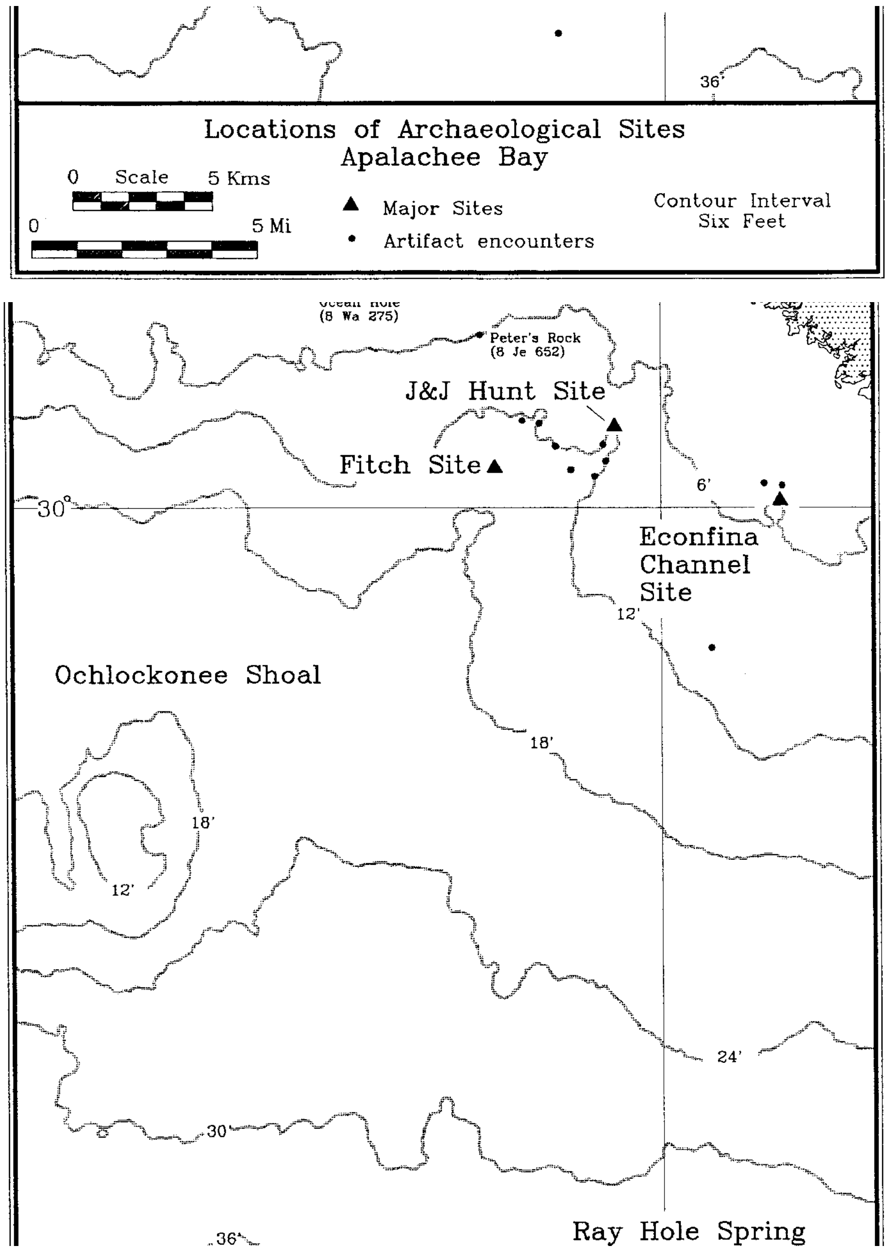

Figure 4. Locations of the known archaeological sites of Apalachee Bay, northeastern Gulf of Mexico, including those described in text. Bathymetric contours in feet, from NOAA charts. Location is outlined by rectangle in Figure 1.

fanning these units were collected, as well as other anomalous items such as animal bones, wood fragments, and any possible manuports. One-liter sediment samples were also taken at many of these locations. The detailed analysis of these sediment samples is reported elsewhere (Faught, 1990, 1996).

Some exposed segments of relict river channels were encountered while towing divers near the Econfina Channel Site. Sea grass or exposed bedrock marked the margins, and clean sand was found in the channel thalweg. Other possible channels were located by fathometer transects, but the extent of these segments was difficult to perceive by direct diver observations due to their patchy nature and obscuration by marine sediments. These small sections of exposure did not provide an analog of the Page/Ladson Site sinkhole, nor sufficient information to reconstruct the pattern of the past drainage system.

Randomly placed, 1×1 m induction dredge excavation units were also placed into sediments at the Fitch and Econfina Channel Sites ($n = 3$ and $n = 7$, respectively) to search for deep river channel sediments and/or possible *in situ* terrestrial sediments with artifacts. These exposures varied between 0.6 and 1.6 m in depth. However, these excavations also failed to find deep river or relict terrestrial sediments and bottomed in either dolomite cobbles or limestone bedrock. Three additional exposures were placed on the margins of the channel feature at the Econfina Channel Site, among karst voids of varying scale. Combined, these exposures contributed to our understanding of the depositional regimes to be found in this submerged karst topography and of the nature of the disturbance of these archaeological sites by inundation. They did not, however, result in the discovery of a sinkhole feature similar to that of the Page/Ladson Site which could be targeted for additional excavation.

Low altitude flights and examination of aerial photos taken in 1984 for the Sea Grass Baseline Study were also employed to delineate the Apalachee Bay paleodrainage network (Continental Shelf Associates, 1985). Some gains were made in understanding the local geomorphology through these methods, particularly the confirmation of exposed channel segments at the confluence of the paleo-Pinhook and paleo-Aucilla River channels (Figures 5, 6, and 7). However, the general disturbance of the ocean surface by waves, unacceptable light reflection angles and water discoloration precluded this medium as a viable tool for additional survey and excavation.

Systematic Survey Methods

Because the more or less random survey and excavation projects and unsatisfactory aerial photos failed to find areas indicative of a drowned sinkhole analog to the Page/Ladson Site, or to clarify the pathway of the paleo-Aucilla drainage, a more sophisticated research design was established. Previous research undertaken by others offshore of the Sabine River of Louisiana had

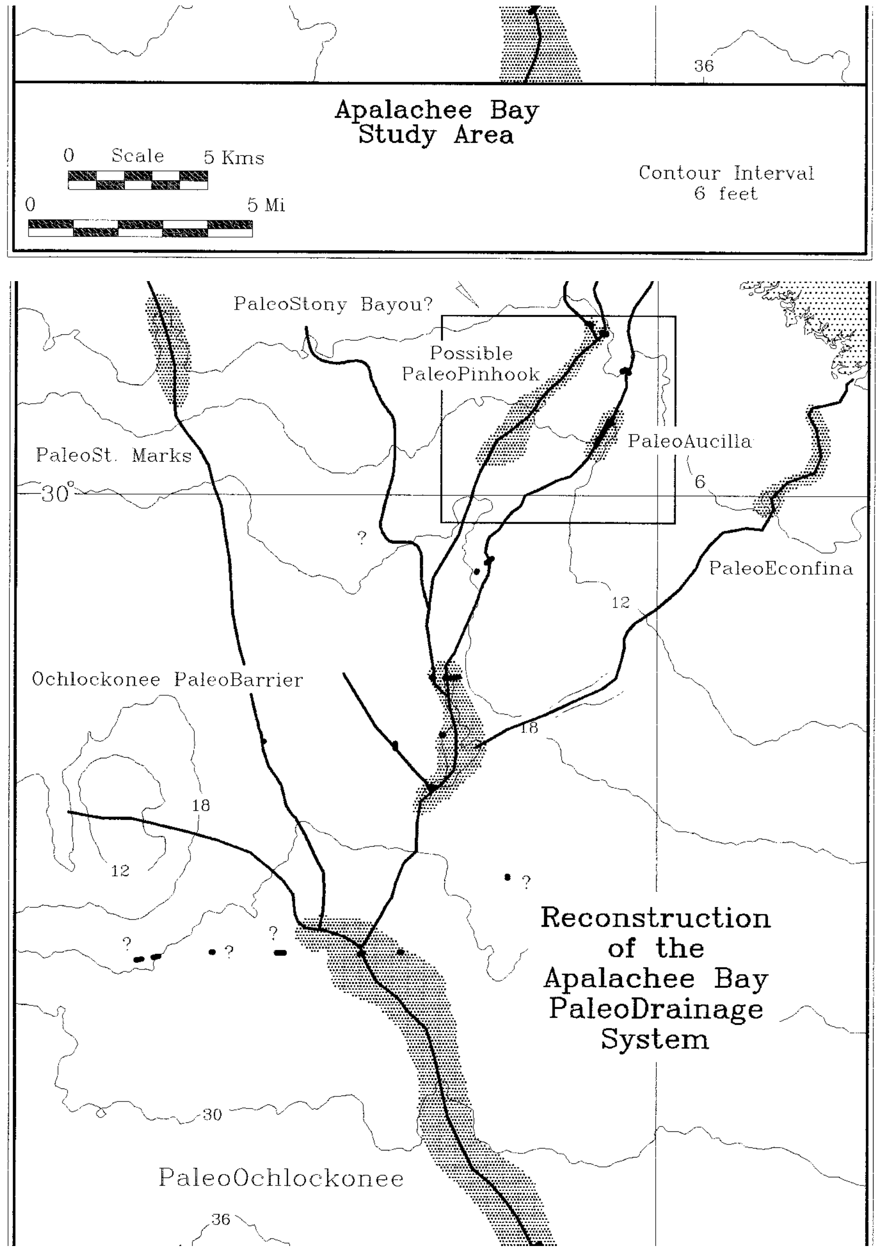

Figure 5. Reconstruction of the Apalachee Bay paleodrainage system, based on subbottom seismic data and bathymetry. Patterned areas are channel segments that were well defined in the seismic data. Location of Figure 6 is shown in outlined area.

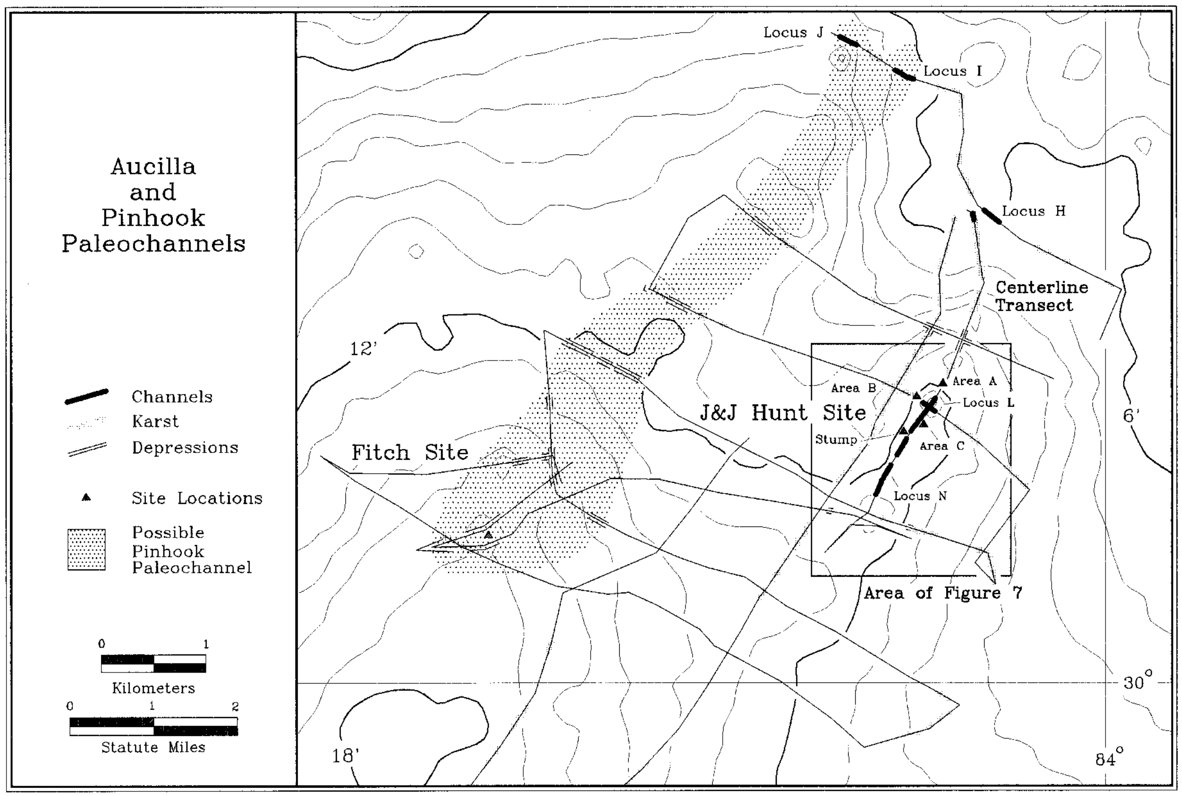

Figure 6. Detail map of the area outlined in Figure 5, showing the Aucilla and Pinhook River paleochannels. Locations of the Fitch and J&J Hunt Sites are indicated, plus associated subsurface channels and karst features, as defined by the seismic data. Thin lines delineate some of the seismic tracklines. Bold lines locate prominent channel features. Labeled locations are described in text. Bathymetric contours in feet, from NOAA charts. Location of Figure 7 is shown in outlined area.

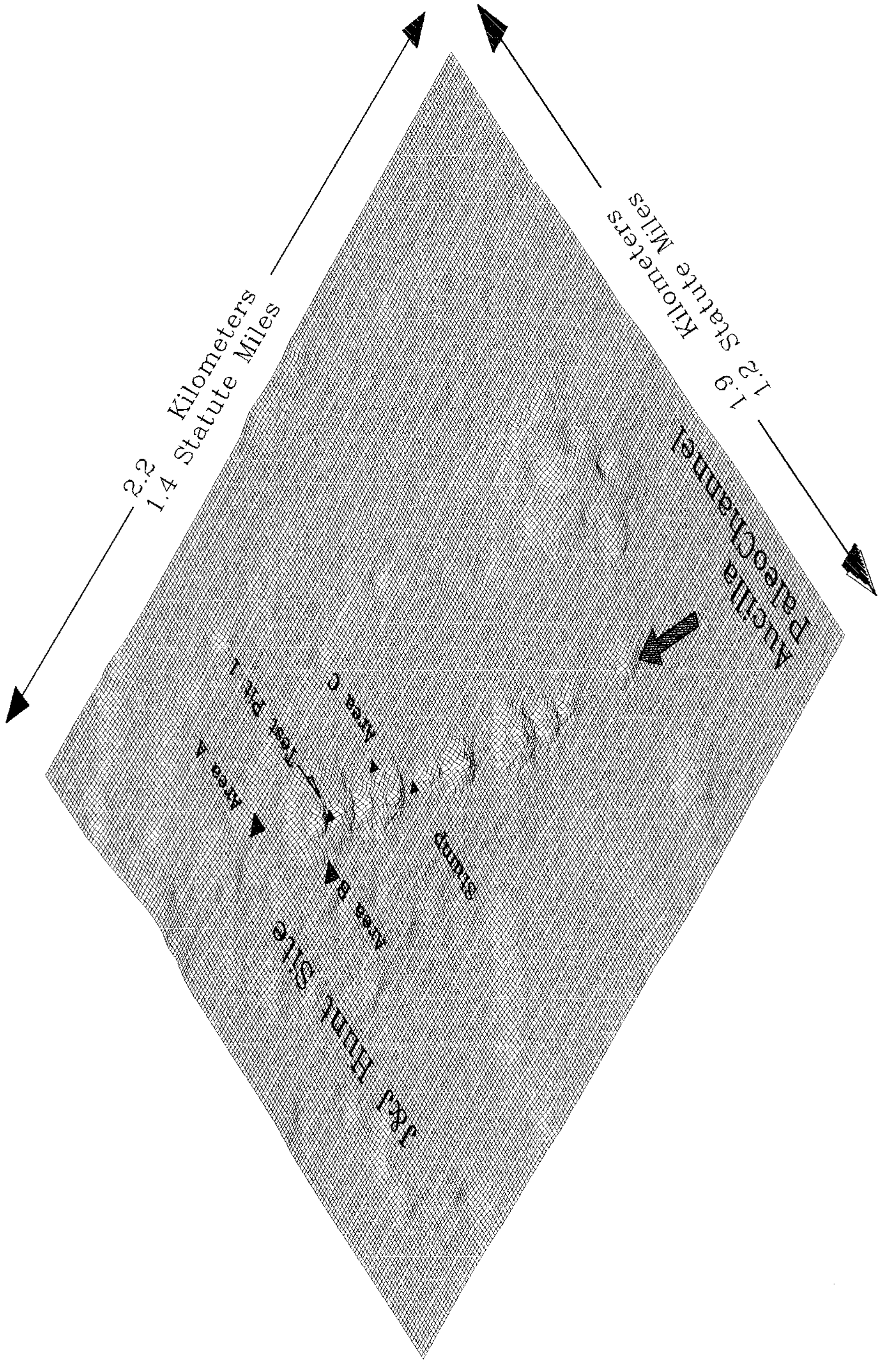

Figure 7. Topographic mesh diagram of the area outlined in Figure 6, showing the Aucilla River paleochannel and locations described in the text.

set a precedent for locating archaeological sites in submerged and buried settings by using subbottom profiling and vibracoring to find and test possible locations for submerged prehistoric sites (Pearson et al., 1986, 1989; Stright, 1986a). We added use of induction dredge excavation strategies to expose the sites, as developed by the Aucilla River Prehistory Project, to produce a three-phase research plan: (1) seismic reflection surveys to locate and reconstruct the paleodrainage system; (2) vibracoring at sites identified using the seismic data, to test the sediments and identify likely sinkholes; and (3) induction dredge test excavations at promising sites to expose possible bone beds and archaeology.

Subbottom profiling was accomplished in 1991 with a GEOPULSE high-resolution, shallow seismic reflection system. Source frequency range was 0.3–2.0 kHz. Maximum penetration was approximately 20 m. Navigational data were recorded every 5 min, and included time, LORAN-C coordinates, latitude/longitude conversions, vessel speed, heading, and fathometer water depth. Seismic activities were curtailed with 3 ft or higher seas, in order to ensure accurate recordings. A total of 111 km of seismic transects were recorded out to a distance of approximately 27 km offshore during this phase of the project.

Computer-aided mapping routines were developed to plot and enhance the submerged topography and paleofluvial features. The topographic mesh diagrams of the sea floor presented here, as in Figure 2, were produced by use of bathymetric data from the NOAA nautical charts of Apalachee Bay (Figure 3) and SURFER, a commercial gridding and contouring program. The grid map images were manipulated as 3-D objects in AutoCAD, a commercial computer-aided drafting program. The subbottom seismic lines and the interpretive data from the profiler record were also manipulated in AutoCAD.

One major objective of this remote sensing activity was to test the hypothesis that the terrestrial karst drainage system, characterized by clusters of sinkholes in linear arrays, continues offshore onto the continental shelf. If that were true, then it would be possible to identify drowned and sediment-filled sinkholes which might preserve *in situ* artifacts and faunal remains. Therefore, seismic transects were run across the expected location of the drowned lower reaches of the Aucilla River paleochannel (Figures 3, 8, and 9). By this means, portions of the Aucilla paleochannel were located, a transect was run down an estimated centerline of one proposed discontinuous segment, and previously unidentified sinkholes were located therein (Figure 6).

After subbottom profiling had defined the channel trend at the J&J Hunt Site, the channel margins and channel depressions were confirmed and marked by divers. Next, survey transects radiating away from the identified paleochannel margins were sampled by hand fanning at regular intervals of 10 or 20 m. One outcome of these procedures was the discovery of a cluster of artifacts designated as Area B, which occurred between 115 and 150 m west of the paleochannel margins (Figures 6 and 7). The base of a fluted

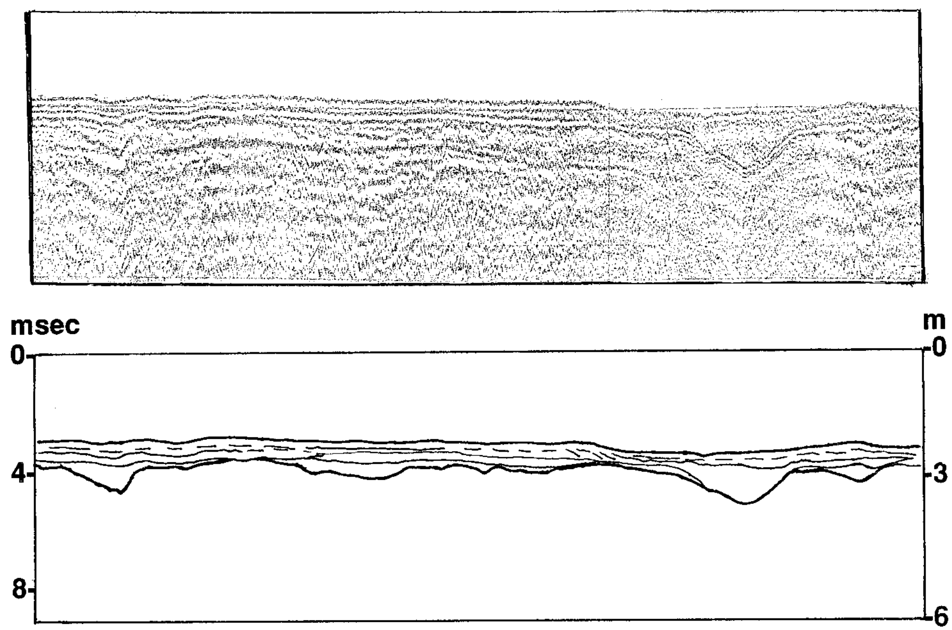

Figure 8. Subbottom seismic profile from Apalachee Bay, showing cross-sections of filled fluvial channels in upper part of paleo-Aucilla River drainage. Location is indicated as Locus I in Figure 6. Seismic record is shown in upper panel, with interpretation in lower panel. Two-way travel time (ms) is given at left side, approximate depth in meters below MSL at right. Width of profile is approximately 940 m.

biface or possibly of a fluted projectile point was also found by this method farther south along this same paleochannel segment, at a location designated as Area C (Faught, 1992).

Vibracoring, the second phase of the investigation, concentrated on the Aucilla paleochannel segments identified in the subbottom profiling Centerline Transect, especially in one of the largest features, designated as Locus L (Figures 6 and 9). The vibracoring device consisted of a vibrating head powered by an 8 hp gasoline engine and bolted to aluminum tubes of 3 in. diameter and 30 ft length (Lanesky et al., 1979).

Due to the limited area within which to find deep sediments, the core tubes were manipulated into the channel by divers. Navigational control included: LORAN-C coordinates, depth and time, core penetration depth, recovery depth, and north orientation. Seven cores were retrieved by this method. Radiocarbon, pollen, and foraminifera/ostracode analyses were performed on sediments from one of these cores, Core 91-3 (Faught, 1992, 1996).

In 1992, a 2 × 2 m induction dredge test pit was excavated at Locus L, at the J&J Hunt Site, to a depth of 3 m, in an attempt to discover *in situ* materi-

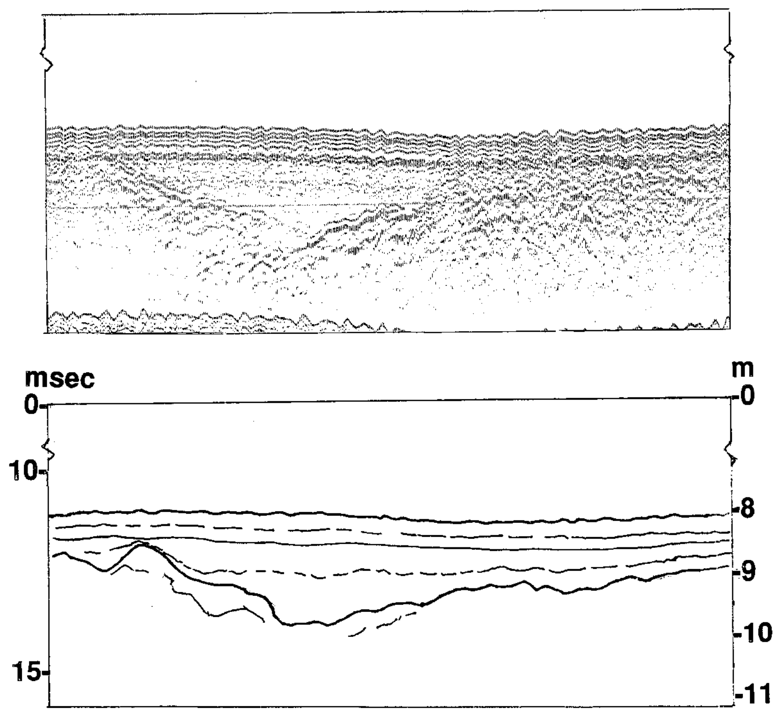

Figure 9. Subbottom seismic profile from Apalachee Bay, showing a cross-section of a large filled fluvial channel in the drowned lower reaches of the paleo-Aucilla River drainage. Irregular paleotopography is caused by karst dissolution of underlying Tertiary carbonate bedrock. Location is near Locus Y in Figure 3. Seismic record is shown in upper panel, with interpretation in lower panel. Two-way travel time (ms) is given at left, approximate depth in meters below MSL at right. Width of profile is approximately 240 m.

als and as the third part of the investigation methodology. The intention was to place this test unit at the downstream, sloping margins of the sinkhole, analogous to settings where river divers have often reported abundant cultural remains onshore (Waller, 1983). In addition, another 1 × 1 m exposure was made near Area C (Figure 6), which determined that the stump of an oak (*Quercus* sp.) tree found in 1991 was *in situ*. Oaks, which grow in present-day Gulf coastal environments, can be used as upper limits for sea level. The oak stump was found at −4 m (−13 ft) water depth (Faught, 1992).

RESULTS

Paleofluvial System

Several features of the drowned late Quaternary coastal plain of Apalachee Bay are revealed in the bathymetric enhancement shown in Figure 2. Submerged extensions of the St. Marks and Aucilla drainages show possible channels offshore, as do some of the smaller watercourses (e.g., Pinhook River and Sulfur Creek channels). The St. Marks River Channel (upper left corner) has been partly dredged and therefore appears exaggerated; the channel nonetheless exhibits sinkhole features. Numerous offshore sinkholes in the vicinity of the paleo-Econfina River channel (location in Figure 5) show up well in the bathymetric enhancement. These features have been confirmed by diver observations, fathometer surveys, and aerial photo analysis. This area is labeled as the "Econfina Karst Field" in Figure 2. Several depressions similar to this "karst field" occur in the southwest corner of the study area as well, and may be another region of sinkhole development.

The Ochlockonee Shoal is another prominent topographic feature labeled on the mesh diagram. This feature, also seen in Figure 3, may represent a drowned barrier island of middle Holocene age, and apparently covers paleofluvial features and possible archaeological sites. Our unpublished vibracore studies of the shoal indicate that it is an anomalously thick deposit of clean sand directly overlying limestone of Tertiary age. All of the above features appear to be part of the drowned lower reaches of the Ochlockonee River, whose present-day mouth is located approximately 5 km west of the western boundary of Figures 3, 4, and 5.

The "Ray Hole trough" shown in this mesh diagram, so named due to its presence near the underwater spring and archaeological site described above, is a large depression representing a paleofluvial feature not recognized before this enhancement. A seismic survey run by one of the authors (J.F.D.) recently near Ray Hole Spring confirmed the presence of paleofluvial geomorphology in the subsurface within the confines of the "trough" defined by the mesh diagram.

Analysis of subbottom profiler transects of Apalachee Bay revealed generally flat-lying subbottom reflections, interrupted by three kinds of seismic anomalies: channels, karst topography, and isolated sinkholes, as shown in Figure 3. Other topographic features defined in the analysis were low relief "depressions" and "hills" (Figures 6 and 7). The channel crossings observed in the seismic records ($n = 34$) are sediment-filled and stand out as distinct "v" or "u" shapes on the subbottom profiles, depending on the angle at which the tracks crossed the feature. The paleochannels appear v-shaped when the track is perpendicular to the flow trend (Figure 8) and more gently concave if the encounter is more nearly parallel to the past channel flow direction (Figure 9). Loci Q, R, S, and T (Figure 3) were confirmed as channel features from the aerial photographs, while diver observations secured the interpretation of paleofluvial channels at Loci L and T. This ground-truthing included the facts that the flat sea floor bottom morphology often deepened slightly in the channel, surface sediments were often finer textured in a channel than on its margins, and either sea grass or exposed bedrock often defined the channel margins. Two of the loci exhibited deep sediments when probed with the vibracore. Twenty-seven seismic anomalies were classified as "sinkholes" (Figure 3) because they exhibited distinct boundaries which were similar to channels, but they were smaller and not on the apparent flow trend of the drainage system (Steeples et al., 1984).

Areas of karst topography identified in the seismic records (n = 106) consisted of unique textural patterns in the records, less clearly defined than channels, but distinct from the surrounding flat seafloor topography and the subsurface limestone morphology. We infer that these patterns represent karst solution and/or collapse structures, or exposures of rocky outcrops, such as described by Popenoe et al. (1984). The principle explaining the texture is that remnant limestone—isolated by the solution and/or collapse of the surrounding rock—returns "point source" signals which are recorded as parabolas. Thus, the texture of these signals appear as "ripples" in the seismic records. Diver confirmation of these anomalies as karst has not yet been made.

The "Centerline Transect" (Figures 6 and 7) substantiated the hypothesis that local karst drainage systems include arrays of sinkholes in linear alignments. Whether such alignments are controlled by regional joint systems has not been established, due to a scarcity of information on joint patterns in the subsurface. A portion of the Aucilla River paleochannel, shown in Figures 6 and 7, is a prime example of such a feature. The approximate length of the channel segment shown in the figures is 1.25 km, beginning approximately 6.5 km offshore from the mouth of the modern Aucilla River (Figure 3). It includes approximately nine sinkholes, including five large ones.

Figures 6 and 7 show that seismic transects "downstream" of this segment encountered few channel features and that the J&J Hunt Site lies directly in line with the paleochannel centerline but on somewhat higher ground. Some features were encountered "upstream"—closer to the modern coastline—but they are of significantly lower relief in comparison with the other channel segment features. Another seismic line was run parallel to the Centerline Transect (Figure 6), and while this line did reflect large areas of point source returns (karst), it did not reveal any obvious channel morphologies.

This suggestion of discontinuity in the paleoriver's path carries with it the implication that there would have been a "rise" of effluent ground water at the beginning of the segment (Locus L) and a "siphon" of influent water at the end. This situation is identical to segments of the modern lower Aucilla River, such as the "Half Mile Rise" section where the Page/Ladson Site (8 Je 591) is located, or the "Little River" section downstream (Willis, 1988). This offshore submerged segment would have existed as a discontinuous feature when sea level was lower and the shoreline farther out on the continental shelf. With transgression, the channel segment probably connected hydrologically through to the next segment inland, not unlike a "ria cycle" in alluvial settings (Kraft, 1986; Pearson et al., 1986). Locus L is one of the largest features of any of those observed from the mouth of the Aucilla to the end of this segment. The sinkhole of Locus L is, therefore, an analog of the Page/Ladson Site and an ideal place to place test excavations searching for the remains of Pleistocene animals and evidence for human activities—as was carried out in 1992.

West of the Aucilla paleochannel there is a cluster of topographic and seismic anomalies including numerous depressions, hills and karst topography, but no sediment-filled channel features (Figure 6). These features are associated with the Fitch Site (Figure 4), a possible Early Archaic chert quarry to be described, and may represent a scoured segment of the Pinhook paleodrainage system (Figure 5). Frequent rock outcrops were also reported by diver/observers in the southern portions of this area, around the Fitch Site (Faught, 1990). Because much of this detail has come from the analysis of the subbottom seismic record, after the last field excursion, more diver observations will be necessary to clarify and investigate these interpretations.

A suggested reconstruction of the paleochannel configuration for our study area is presented in Figure 5. Channel segments farther south (e.g., Loci Y or BB in Fig. 3) appear to be more similar to the mixed alluvial and karst channels of the modern St. Marks or Ochlockonee Rivers onshore, because of the presence of terraced sediments inferred from the subbottom profiler record. We propose that the ancient St. Marks, Aucilla, and Econfina Rivers were tributaries to this larger paleochannel, which we designate as the paleo-Ochlockonee River channel. Its trend continues south through the "Ray Hole Trough" (Figure 2). The combined flow of these rivers could have created a change in the drainage regime beyond the 24 ft (7.3 m) bathymetric contour, shifting from karst-controlled to mixed karst- and alluvial-controlled drainage characteristics. This would also signal a change in the kind of fluvial model which is to be employed beyond that depth for locating archaeological sites. Again, diver confirmation and coring will be necessary to confirm and expand these interpretations.

Stratigraphy

From the various vibracore and induction dredge excavations, and the seismic data, we have identified two major lithostratigraphic units of sediments that fill offshore karst depressions: sandy biogenic marine sediments overlying gray clays (marls). The clays are inferred to be fresh water deposits, due to an absence of marine fauna, fine grain texture and presence of wood detritus. These two depositional units are gradational, often with an intervening dark-colored zone, or horizon, of organics reflecting the brackish water phase of the transgression. Dolomite cobbles occur with depth in the clays (marls) and are probably the result of recent diagenesis (Coudray and Montaggioni, 1986; Faught, 1996). One exposure, at the Fitch Site, penetrated the dolomite cobbles to discover more clay-rich sediments and the bones of extinct terrestrial fauna below (Dunbar et al., 1992; Faught, 1990, 1996). Detailed descriptions of these sediments are given below.

The lower sediment unit is a gray, often sticky, marl, a calcareous mud which includes 10–20% fine to very fine angular to subangular quartz sand and abundant fragments of organic matter from very small specks of debris, to sticks and even logs of wood. The evidence indicates that this unit was deposited in a quiet, probable fresh water depositional environment. The working hypothesis is that the unit is the result of the precipitation of $CaCO_3$ by algae, but the particular species or environmental conditions responsible for its formation remain to be determined (Gleason and Spackman, 1974; Purdy, 1991). Analysis for fresh water species of foraminifera and ostracodes was undertaken, but none were found to be present. Other descriptions of this unit, some with differing interpretations, have been published in coastal settings further south in the mouth of the Crystal River by Hutton et al. (1984) and in other locales in southwestern Florida (Evans et al., 1985, 1989; Hine et al., 1988; Gleason and Spackman, 1974).

Pollen preservation is excellent in this marl unit. In general, there are high frequencies of pine (*Pinus*) pollen (68%) in the lower portions of the clays. Cypress (*Taxodium*) pollen is present, but not dominant throughout the gray clay until the uppermost brackish zone, where it becomes dominant (77%). Radiocarbon control from this unit rests on four determinations which average about 7000 yr B.P., although one date is inverted (Table I). Another radiocarbon date was documented by Hoenstine and Garrett (1993) from similar sediments closer inshore: 6920 ± 195 (no sample number available). Based on these dates, the pollen record correlates well with other regional early middle Holocene assemblages which reflect high pine pollen frequencies such as those at Camel Lake or Lake Louise (Watts, 1971; Watts et al., 1992).

Initially, these gray clays were erroneously correlated (chronologically) to similar gray marly clays known from the nearby Page/Ladson Site. In this onshore setting, these clays have a secure radiocarbon chronology within the early Holocene (Faught, 1992; Dunbar et al., 1988). Therefore, the ^{14}C dates point to a lithostratigraphic, not chronostratigraphic, relationship.

The gray, silty clay marl grades to marine sandy sediments over a zone or horizon of darker color in cores and induction dredge exposures at the J&J Hunt Site (Figures 7, 10, and 11). This zone includes abundant fragments of organic debris, wood, and increased frequencies of *Crassostrea* individuals and fragments. The sediment texture grades from the gray silty clay to the upper marine sands over a 10–15 cm transition zone. The foraminifera and ostracodes identified in this zone include quiet water, brackish species (e.g., *Cyprideis americana*). Arboreal pollens in this zone species were dominated by cypress. Pine pollen frequency declined substantially when compared with percentages in the samples from the lower clay units. This pollen analysis also showed that the absolute frequency of pollen grains and charcoal fragments increased dramatically in this organic zone. We suggest that this zone represents the brackish water stage of the inundation sequence, as expressed by the marsh grass zone of the modern coast, although a direct modern ana-

Table I. Radiocarbon data from archaeological sites in Apalachee Bay, northeastern Gulf of Mexico (dates in uncorrected radiocarbon years).

Sample	Radiocarbon Date (yr B.P.)	Lab No.	Depth (MSL)
Marine Samples			
Wood in marine sand deposit Econfina Channel	5140 ± 100	A-4696	6 ft (1.8 m)
Wood in marine sand deposit J&J Hunt site	6100 ± 60	AA-11048	12 ft (3.7 m)
Crassostrea shell, at surface Area C, J&J Hunt site	6135 ± 80	AA-10508	14 ft (4.3 m)
Crassostrea shell, 30 cm below surface, Area C, J&J Hunt site	6375 ± 80	AA-11045	15 ft (4.6 m)
Brackish-Water Samples			
Wood from dark gray silty clay marl Locus L, Core 91-3	6785 ± 80	AA-8859	18 ft (5.5 m)
Wood from dark gray silty clay marl Locus L, Test Pit 1	6825 ± 120	AA-10510	22 ft (6.7 m)
Terrestrial Samples			
Wood in gray fine sandy clay Locus L, bottom of Core 91-3	7130 ± 75	AA-8872	21 ft (6.4 m)
Wood in gray fine sandy clay Locus L, Test Pit 1	7160 ± 95	AA-10511	23 ft (7.0 m)
Wood in gray fine sandy clay Locus L, bottom of Test Pit 1	7010 ± 80	AA-11047	24 ft (7.3 m)
Wood in gray fine sandy clay Locus L, bottom of Test Pit 1	6755 ± 60	AA-10513	25 ft (7.6 m)
Quercus stump Area C, J&J Hunt site	7240 ± 100	A-6714	14 ft (4.3 m)

log for this deposit has not been observed. The approximate middle of this brackish zone (−21 ft msl; −6.4 m) in Test Pit 1, Locus L, was used for some paleo-sea-level estimates to be described below. Radiocarbon dates from this zone average approximately 6800 yr B.P. (Table I).

The uppermost stratigraphic unit is a sandy biogenic deposit, often called "shell hash," which reflects fully marine conditions. This sedimentary unit occurs in and on bedrock exposures and in karst solution voids of varying sizes. It is characterized by brown sands of medium texture and marine shell inclusions. At the Econfina Channel site (−6 ft msl; −1.8 m) *Crassostrea* sp. (oysters) dominated, although *Pecten* sp. (scallops) were also present. At the J&J Hunt Site (−12 to −15 ft msl; −3.6 to −4.6 m) *Pecten* dominated, and

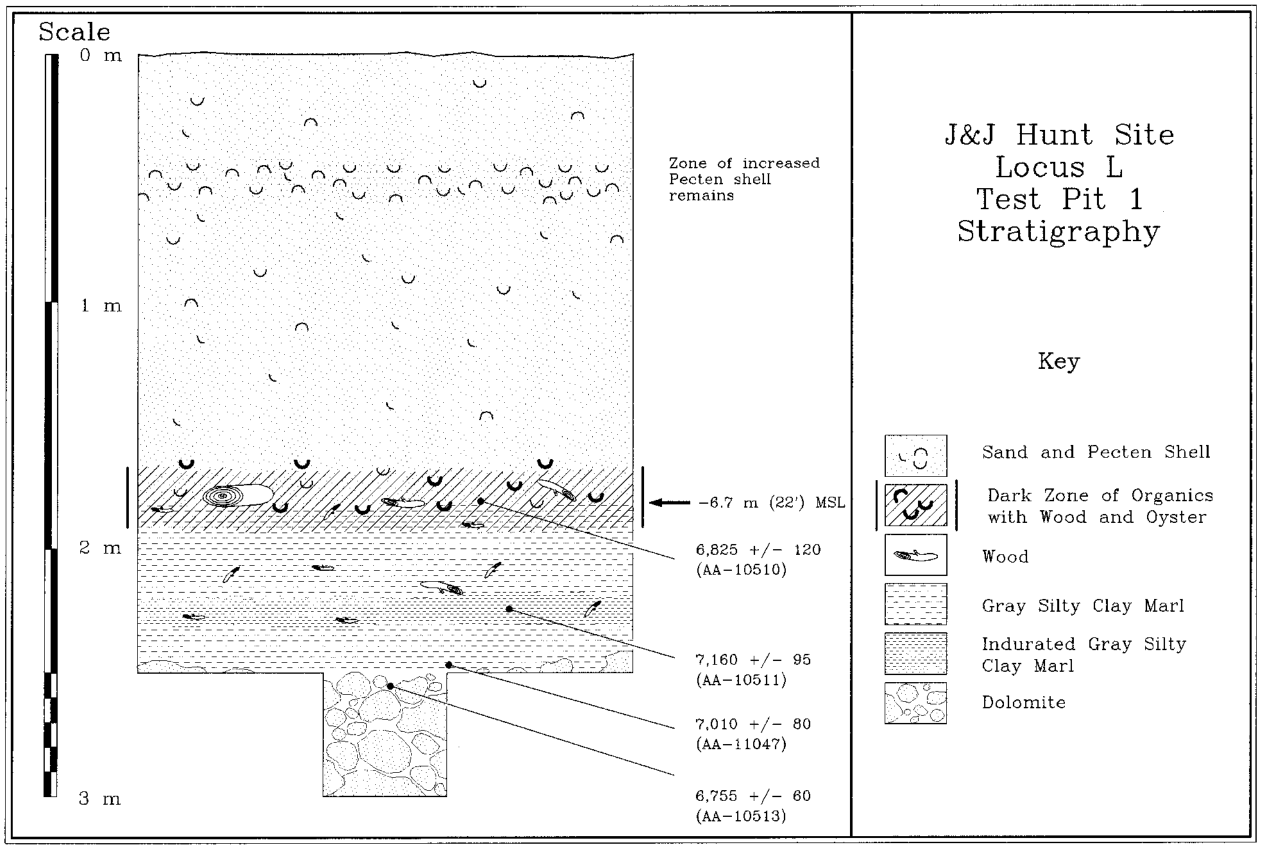

Figure 10. Stratigraphic profile of Test Pit 1, Locus L_1, J&J Hunt Site, showing position of dated materials. Scale at left indicates subbottom depth in test pit. Location of site is shown in Figures 6 and 7.

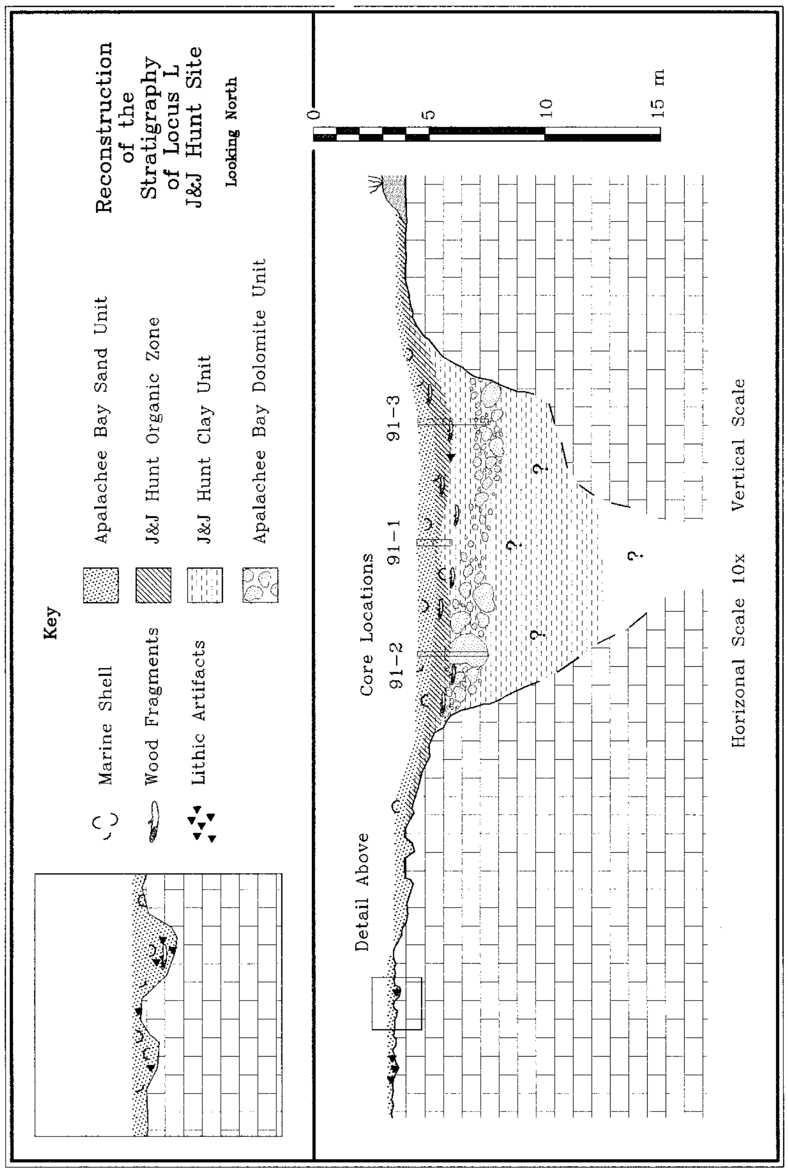

Figure 11. Reconstruction of the buried sinkhole at Locus L, J&J Hunt Site. Scale at right indicates depth below mean sea level. Location of site is shown in Figures 6 and 7.

Crassostrea were present on the surface. More diversity of species and more immature individuals were observed at the Fitch Site including occasional *Pecten* (relict?), abundant immature *Crassostrea* shells, numerous *Chama,* spiny slippers, and cockle. Some *Arca* sp. (turkey wings) and gastropod varieties are also present. Deceased individuals of branching rose corals (*Hydrocoralline* sp. or *Astrocoenia* sp.?) were frequent in the marine sediments at the Fitch and J&J Hunt Sites. However, no living examples of this assumed deeper water species were observed at either site, and no examples (living or deceased) were observed at Econfina Channel. Foraminifera and ostracode analysis of these sediments at Locus L also reflects a fully marine environment (Palacios, personal communication, 1996). No pollen samples were analyzed from this unit. Radiocarbon dates on shell and wood from this zone vary between approximately 6000 and 5000 yr B.P. as shown in Table I.

In virtually all stratigraphic exposures at all three sites, soft to firm rounded pebble to cobble size clasts of dolomite were encountered with depth in the sediments. The origin of these dolomites is problematic. One explanation is the possibility that they are erosional debris from local dolomite outcrops of Tertiary age, contributing colluvium to the sedimentary column. An alternative hypothesis is that they are syngenetic or diagenetic deposits formed as products of the inundation. Thin section microscopy of the dolomite revealed few rhomboids in the interstitial spaces of the clasts, suggesting a recent origin in either subaerial or, more probably, brackish conditions. Rhomboids form gradually over time between dolomite particles; they are rare in recent dolomites and more common in ancient dolomites (Coudray and Montaggioni, 1986). One exposure, at the Fitch Site, penetrated the dolomite layer to reveal more clay-rich sediments and the bones of extinct fauna, including *Eremotherium* (sloth), *Sirenia* (Dungong), *Equus* (horse), and *Paleolama* (camel) (Dunbar et al., 1992; Faught, 1996). Combined, these observations suggest that continued excavations below the dolomite in appropriate settings should reveal older, possibly Pleistocene sediments and artifacts of Paleoindian or Early Archaic age.

Archaeology

As stated previously, the discovery of marine inundated prehistoric archaeological sites was the major impetus for this research. Systematic collections at the Fitch, J&J Hunt, and Econfina Channel sites have resulted in a total of almost 1700 artifacts (Figure 4). These artifacts were found in clustered surface arrays not unlike plowzone assemblages in terrestrial settings, and they have included diagnostic chipped stone tools representing Paleoindian, and Early and Middle Archaic-aged activities (Faught, 1996). Nondiagnostic, isolated chipped stone artifacts were also encountered at 15 other locations in the research area, all around chert outcrops, and all inferred as the results of quarry activities (Faught, 1988, 1996).

The chipped stone debitage from these collections was counted, weighed and sorted into four categories of debitage (Sullivan and Rozen, 1985). Detailed analysis was also performed on the chipped stone from the J&J Hunt and Econfina Channel sites, which included studies of platform edge treatment, platform blow angle and type, and possible use wear patterns. These analyses were performed to determine the lithic reduction strategies and the kinds of activities that took place at the sites (Faught, 1996).

The Fitch Site (Figure 11), 10 km (6.2 statute miles) from the mouth of the modern Aucilla River, at −17 ft msl (−5.2 m), appears to be the remains of a large lithic quarry of unknown age. Artifact density was substantial (n = 11/m^3), but no artifacts of clear diagnostic value were located. Artifacts were found on bedrock exposures, as well as on and in the upper 10–15 cm of the marine sediments surrounding them. It may be that marine processes, such as storm surges, moved and sorted the items out and onto the marine sediments, because artifact size decreased on average with distance from the bedrock exposures (Faught, 1996). At least two flake cores and several large flakes were collected at Fitch, some exhibiting bladelike flake reduction techniques (Daniel and Wisenbaker, 1987). In light of the sea-level data to be discussed below, we suggest the site is older than 7500 yr B.P. The lithic reduction strategies suggest earlier, possibly Paleoindian or Early Archaic age.

The Fitch Site (Figure 11) was probably occupied in an inland setting, when sea level was considerably lower than present. Human activities possibly took place away from any major drainages, in contrast to the settings of the J&J Hunt Site and Econfina Channel, which were both near the margins of fluvial features. Because the surrounding bedrock exhibits substantial amounts of medium to fine-grained chert raw materials, we infer that the Fitch Site was a large quarry site, although the frequency of cortex was generally low. On the other hand, the site is located within the southern (downstream) portions of the Pinhook River paleodrainage feature described above (Figure 5), and there may have been special plant or animal communities, or both, within the confines of this geomorphologic feature in the past.

Based on fracture characteristics of many of the chert artifacts it may be that quarry or other stages of the chipped stone reduction sequence included intentional and controlled heat fracturing (Faught, 1990, 1996). The potential for lithic resource procurement and flint knapping by the use of heat fracturing has been documented by Purdy, but further testing is necessary to confirm this (Purdy, 1981). It may be that the particular spot we surveyed was a locality of primary reduction within a larger, possibly compartmentalized, archaeological site. Therefore, evidence for secondary reduction and possibly diagnostic items might be found elsewhere in the immediate area.

Sea-level change apparently disturbed the Fitch Site more energetically than the other sites observed. The movement of items appears to have occurred during a post-inundational event or process rather than due to transgression, because the cultural items lay *on* marine sediments in some collection and excavation units. For this reason, it may also be that smaller items are to be found with greater distance from the original collection transects. The Fitch Site remains an enigma demanding further scrutiny.

At the J&J Hunt Site (Figures 6, 7, and 10), artifacts were encountered around the margins of the discontinuous channel segment 6.1 km (3.8 statute miles) from the mouth of the modern Aucilla River in 12 ft water depth. Based on all the evidence at hand, Area A (located NNE of the sinkhole at Locus L) represents an occupation during Early Archaic time, by people who made Bolen projectile points and unifacial scrapers, including a diagnostic Hendricks scraper (Bullen, 1975; Purdy, 1981). Area B, on the other hand, is located NNW of the Locus L sinkhole and may represent slightly earlier toolmaking activities by people who made Suwannee projectile points and unifacial scrapers. This interpretation is based on the presence of a thumbnail scraper and a Suwannee preform among the debitage (cf. Daniel et al. [1986] for an explanation of Suwannee reduction strategies). The base of a fluted biface was found on the eastern margins of the channel segment at Area C (Figure 6), supporting the interpretation that Paleoindians and their progeny were around the channel segment identified at the J&J Hunt Site (Faught, 1992).

Area B artifact density was quite concentrated, approaching 9 items $m^3 \times 10^{-1}$, whereas Area A exhibited more dispersion and an artifact density of 3 $m^3 \times 10^{-1}$, Study of the debitage revealed that Area B exhibited mostly bifacial reduction strategies from biface blanks, whereas Area A produced evidence for secondary lithic reduction activities using angular blocks of chert and then chipping to bifaces, probably biface blanks. The debitage from Area A also exhibited some evidence for tool edge maintenance, more so than the artifacts from Area B, but both were low in frequency. Some reduction of animal bone may also have been taking place at Area A based on the presence of short pieces of unidentifiable terrestrial mammal long bones.

Activities at Area B possibly took place in time before those at Area A, on the basis of diagnostic artifacts. Shorelines during the Paleoindian period would have been some 130 km (80 statute miles) further seaward, based on the sea-level data presented below. The Paleoindian shoreline, therefore, would have been at the modern 40 m depth contour. Area A was probably occupied between 10,000 and 9000 yr B.P., on the basis of the diagnostics, with activities taking place around the margins of the initial (upstream) sinkhole of the discontinuous segment. The coast would have been about 50 km (30 statute miles) farther offshore from the modern coast (i.e., at approximately the present-day 20 m contour). Finally, a projectile point of probable Middle Archaic age and a broken deer antler were located near the oak tree stump at Locus L by random hand fanning. These items suggest the presence of humans around these karst features during the final stages of inundation.

At the Econfina Channel site chipped stone items were found near relict drainage features. Based on an analysis of the chipped stone debitage and tools (Faught, 1996), the evidence suggests that the assemblage represents the remains of a small Middle Archaic period special activity locus or field camp, located on the margins of the paleochannel of the Econfina River, or perhaps on a tidal creek of the paleo-Econfina. The site is located 4.7 km (2.9 statute miles) from the mouth of the modern Econfina River and is probably older than the radiocarbon date of 5140 ± 100 yr B.P. obtained from wood found in the marine sandy shell "hash" slightly farther upstream. We suggest a date sometime between 6500 and 5500 yr B.P. for this occurrence.

The inhabitants of the Econfina Channel Site were people who made Marion or Putnam projectile points/knives (Bullen, 1975). They were knapping flint from nearby outcrops and possibly sharpening some chipped stone tools near this area based on observations of the edge treatment and condition of the biface flakes. The frequency of cortex was high for the assemblage, and chert resources were identified in the field. Oyster shells found at the Econfina Channel Site probably represented expedient subsistence refuse. Fish and apple snail remains in the associated sandy shell deposits also suggests food discard. Data presented by Russo et al. (1992) confirm the use of both fish and apple snails in late Middle Archaic contexts from the Groves' Orange Midden Site of similar age and culture on the eastern side of Florida.

Sea-Level Rise

As noted, the first two parts of this research focused on the determination of the trend of the early to mid-Holocene paleochannels and the discovery of archaeological sites using a model based on terrestrial analogs. The final aspect of this geoarchaeological approach to marine inundated prehistoric archaeology is to reconstruct the inundation of the shelf during Holocene marine transgression and to assess the site formation processes.

A summary of sea-level curves from the northern Gulf of Mexico and elsewhere, along with various data points from other studies in the Apalachee Bay region, is presented in Figure 12. The figure also includes a short section of a local sea-level curve constructed using the dated materials discussed above.

Sea-level rise over the late Wisconsinan continental shelves began about 18,000 years ago (Fairbanks, 1989). Sea-level studies from the Gulf of Mexico indicate that the inundation may have occurred in pulses, interrupted by stillstands, lasting approximately 1000 years (Figure 12) (Frazier, 1974; Curray, 1960; Nelson and Bray, 1970; Rehkemper, 1969). The effect of this rapid late Wisconsinan sea-level rise on the shelf can be deduced from oxygen isotope data in sediment cores collected in the northern Gulf of Mexico. These records indicate that warming caused meltwater influx to the Gulf of Mexico

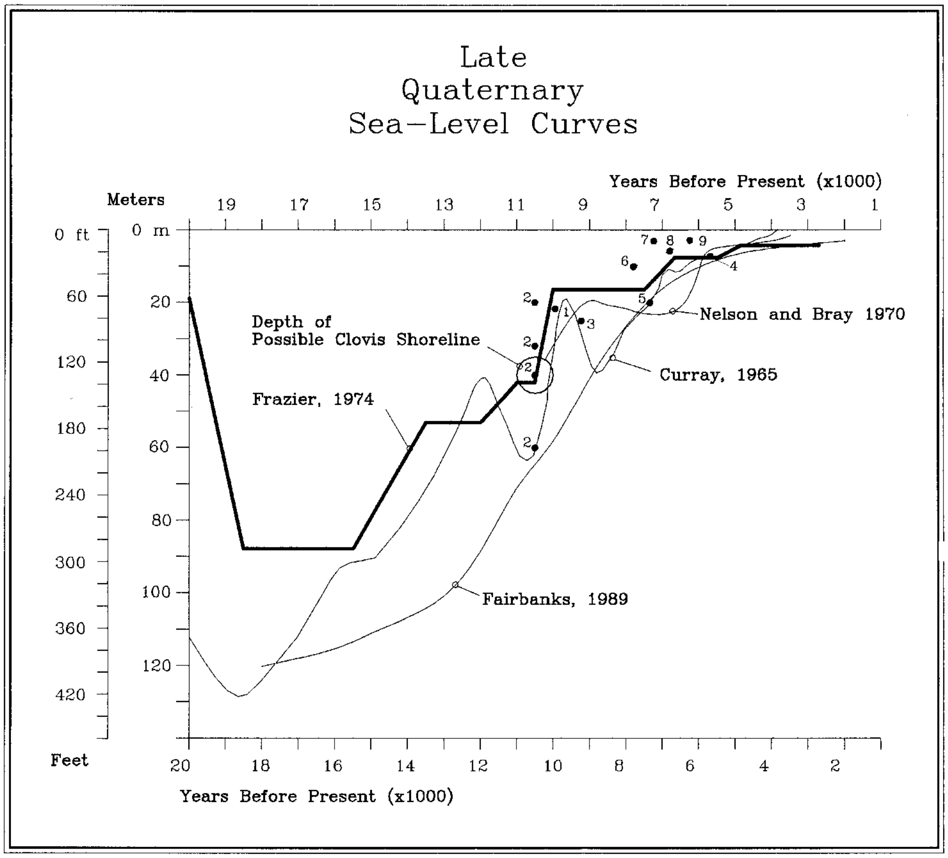

Figure 12. Late Quaternary sea-level curves, including dated materials from this research. Depth below present MSL is indicated in meters and feet at left. Chronology is in uncorrected radiocarbon years B.P. Individual numbered points refer to sea-level data points from the northern Gulf of Mexico and north Florida region, all of which are described in text: (1) Apalachicola River area, Florida (Schnable and Goodell, 1968); (2) undated geomorphological evidence for stillstands, western Florida continental shelf (Ballard and Uchupi, 1970); (3) Santa Rosa Island, Florida (Otvos, 1991); (4) Biloxi Bay, Mississippi (Otvos, 1991); (5) Cape Canaveral, Florida (Field, 1974) (6) = mean of two dates from Ray Hole Spring site in Apalachee Bay, Florida (described in text) (Anuskiewicz, 1988; Anuskiewicz et al., 1994); (7) *Quercus* stump near Area C, J&J Hunt site (Table I); (8) mean of two dates on wood from dark gray silty clay marl, Locus L (Table I): (9) mean of two *crassostrea* shell dates, Area C, J&J Hunt site (Table I).

to be extremely high during the period 14,000–12,000 yr B.P. (Emiliani et al., 1978; Leventer et al., 1982). The estimate for ice cap volume loss during that time—more than 30%—corroborates such a conclusion (Cline, 1981). Sediment deposition rates on the continental shelf during that time were also high. Fluvial discharge for the Mississippi River during this period is estimated to have been more than six times present rates, while annual sediment load is estimated to have been as much as thirteen times the present level (Perlmutter, 1985). Much of the near-surface sediment deposits of the northern Gulf of Mexico shelf probably had their origin during this period of high discharge (van den Bold et al., 1987; Donoghue, 1992, 1993).

The rapid late Wisconsinan rate of sea-level rise slowed sometime after about 12,000 yr B.P. A significant change in the general trend of warming occurred at the time of the Younger Dryas (YD), between 11,000 and 10,000 yr B.P. (Edwards et al., 1993). During YD time, drainage down the Mississippi was diverted to the St. Lawrence River in the far northeast, flow diminished substantially, and sea-level rise slowed, stopped, or perhaps even receded. Then, between approximately 10,000 and 8000 yr B.P., the second meltwater pulse occurred, flooding the inner continental shelves. The rate of sea-level rise slowed after this event, until today's sea levels were attained, sometime around 5000 yr B.P.

There is also some evidence for locally higher sea levels in the southeastern United States between 5000 and 2000 yr B.P. The data are limited, but generally consistent. The high-stand evidence comes from beach ridges, wetlands and midden sites (Stapor et al., 1988, 1991; Tanner, 1992; Donoghue and Tanner, 1992; Donoghue and White, 1994; Walker et al., 1994; Brooks et al., 1986; Colquhoun and Brooks, 1986; Colquhoun et al., 1995; Holmes and Trickey, 1974).

Sea-level curves have been compiled for areas of the Northwestern Gulf of Mexico (Curray, 1960; Nelson and Bray, 1970; Frazier, 1974), but records of past sea levels in the eastern Gulf, nearer the research area, are few. Scholl and Stuiver (1967) and Scholl et al. (1969) produced a sea-level curve for the Florida Keys and Everglades for the past 5000 years. Their curve is generally smooth and falls slightly above those included in Figure 12. The sparse sea-level data for the northeastern Gulf of Mexico include Schnable and Goodell's (1968) stratigraphic evidence for brackish water conditions during the early Holocene in the vicinity of the present-day Apalachicola Bay. A *Rangia cuneata* shell from a borehole at that location produced a radiocarbon date of 9,950 yr B.P. at a depth of −22 m msl (Figure 12).

In a bathymetric study Ballard and Uchupi (1970) identified possible barrier spits and other relict coastal features on the western continental shelf of Florida. They described robust development of barrier spits and other coastal features at a common depth of 60 m, and inferred less robust stillstand deposits at the 40, 32 and 20 m isobaths. They also identified a relict feature at a depth of 160 m. Such a depth is well beyond most estimates of sea-level lowering during the Quaternary. The best estimate for the late Wisconsinan sea-level minimun is about −120 m, approximately 18,000 years ago, based on the sea-level record obtained from drowned coral reefs off the island of Barbados (Fairbanks, 1989). Frazier's (1974) sea-level curve for the northern Gulf of Mexico includes stillstands at approximately −53 m (13,500–12,000 yr

B.P.) and −42 m (11,000–10,000 yr B.P.), in rough agreement with the data presented by Ballard and Uchupi (1970).

Another possible paleoshoreline feature in the Northeastern Gulf is a relict reef tract known as the Florida Middle Ground (Figure 1). It is located between the 40 and 50 m isobaths offshore from the study area. The age of this mid-shelf feature has not been established (Back, 1972; Brooks, 1981; CEI, 1977; Jordan, 1952). The reef tract may be part of one of the stillstand shorelines described by Ballard and Uchupi (1970). Donoghue (1993) suggested, based on seismic data and the Gulf of Mexico record of sea-level rise, that the Middle Ground reef was the former location of a late Quaternary paleodelta of the Apalachicola River.

The 40 m isobath lies approximately 150 km offshore from the present mouth of the Aucilla River. Based on the combined evidence from Ballard and Uchupi (1970) and from Frazier (1974), we suggest that the 40 m isobath is the "Clovis shoreline," that is, the coastline approximately contemporaneous with Paleoindian colonization on the northeastern Gulf of Mexico shelf (Figure 1).

Two radiocarbon data points for local sea-level rise come from Ray Hole Spring (Figure 4), located 30.6 km (19 statute miles) offshore in about 10.6 m (35 ft) of water (Anuskiewicz, 1988; Anuskiewicz et al., 1994). Induction dredge excavations at Ray Hole Spring have encountered lithic debitage in the sandy marine shell "hash," and rock fragments in cracks and voids in the limestone bedrock. Oyster shells are found with depth in these voids. Oyster shells are indicative of brackish water coastal environments. One of the Ray Hole Spring oysters returned a radiocarbon date of 7390 ± 60 yr B.P. A large piece of wood (*Quercus*) was found in one void in the limestone bedrock below oysters. Because the wood had not been damaged by marine or brackish water organisms, it was considered by those researchers to have been deposited in a terrestrial or fresh water environment after 8220 ± 80 yr B.P. (the date on the wood). While these items are not strictly *in situ,* the dates are at least secondary sea-level indicators, and they bracket the inundation process at this location. The two radiocarbon dates can be averaged to approximate the age of the brackish phase at that site at 7800 yr B.P. and at a depth of −10.7 m msl. This point is included in the sea-level data presented in Figure 12.

Specific evidence for the timing of sea-level rise determined by the Apalachee Bay research reported herein includes a radiocarbon date on the *in situ* tree stump and associated oyster remains found at the Aucilla paleochannel segment at Area C, as well as the zone of dark organics found in the sinkhole at Locus L (Figure 10). The stump indicates terrestrial conditions, the dark zone of organics brackish water conditions, and the oysters coastal marine conditions. The brackish water sediments constitute a primary sea-level indicator; the stump and oysters are secondary indicators (van de Plassche, 1986).

Radiocarbon analysis of the outer 10 rings of the stump resulted in a date of 7240 ± 100 yr B.P. Hand fanning by divers to a depth of 40 cm around the stump revealed numerous large oyster shells (*Crassostrea rhizophorae*) and abundant fragments of wood. The oyster shells were distributed in a more or less linear fashion for 20–30 m east and west and suggest the presence of an extinct oyster bioherm similar to those living in the marine environment at the mouth of the modern Aucilla River. Carbon dating of the carbonate fraction of the oysters produced dates of 6,135 ± 80 yr B.P. for a sample from the upper 10 cm of the bioherm and 6,375 ± yr B.P. for a slightly deeper sample, documenting complete inundation as described above with reference to Ray Hole Spring. Two dates from the dark organic zone in Locus L (Figure 10) resulted in an average of about 6800 yr B.P. for the brackish phase of inundation at −6.4 m (−21 ft) MSL. Radiocarbon dates from the gray clays, indicating possible freshwater conditions at Locus L, average about 7000 yr B.P., at depths below −21 ft msl (−6.4 m) (see Table I for a summary of these dates).

Based on this evidence it can be estimated that sea level rose approximately 4.3 m during the 1000-year period, or 4.3 mm/yr. This is probably a conservative estimate for the rate of sea-level rise during that period. The various sea level curves shown in Figure 12 indicate sea level rising by as much as 10 m during that time. However, even at 4.3 mm/yr the rate of shoreline retreat would be significant. The gradient of the inner shelf in this region is quite low, approximately 1 : 3000. At a rate of sea-level rise of 4.3 mm/yr, the shoreline retreats nearly 12 m each year. This rate represents a loss of nearly 0.25 km every human generation (20 years).

By contrast, the modern rate of sea-level rise in this region can be reliably estimated from long-term tide gauge records from Cedar Key, near the eastern boundary of Apalachee Bay. There, sea level has been rising by approximately 2.0 mm/yr since the early part of this century, or 2 m/1000 years (Hicks, 1973). Modern rates of shoreline retreat in the region, based on measurement of historic shoreline charts, average about 1–2 m/yr (Donoghue et al., 1990). Thus, for the earliest inhabitants of the northeastern Gulf shelf, the rate of sea-level rise—and shoreline retreat—was at least twice as rapid as, and perhaps many times more rapid than, present rates. At such rates, the early Holocene inhabitants of the northeastern Gulf of Mexico continental shelf must have been fully conscious of, and contending with, the inundation.

It is also of interest that, in general, the Apalachee Bay data reflect shallower depths than either the Frazier (1974), Nelson and Bray (1970), or Curray (1965) estimates for the western Gulf at similar times. These studies were all from the northwestern Gulf of Mexico, where subsidence due to the effect of Mississippi River sediment loading has depressed the margin. This finding is in agreement with Opdyke et al. (1984), who hypothesize regional isostatic rebound in the Northeastern Gulf region due to significant, very late Pleistocene "hypersolution" of the limestone bedrock. Additional data points will be necessary to resolve this issue.

From our pollen analyses it is apparent that the local environment went through several adjustments during the inundation process. The transition included a change of dominance from species-rich forests with frequent pine to dominance by cypress and grasses. Oak pollen abundance remained approximately the same throughout the sequence, suggesting, perhaps, that oak can withstand brackish conditions better than pine. Higher absolute frequency of charcoal fragments in the pollen samples in the brackish zone suggest that dead trees and bushes with inundated bases and exposed canopy skeletons may have caught fire during inundation. This may have been due to human involvement or to natural causes. Due to its subtropical climate, Florida is especially prone to lightning strikes, which can ignite such fires.

A likely scenario is that as the sea transgressed over the marsh grass coastal zone, the peaty sediments within which the marsh grasses grew remained resistant to the inundation process, in contrast to the immediate margins of the creeks and tidal channels. After full inundation, the organic-rich, former marsh sediments may have encouraged the growth of sea grass beds, while the relict sections of paleochannels and exposed bedrock remained barren, such as those found at the Ecofina Channel Site. Test excavations in the sea grass beds may reveal additional, perhaps more intact archaeological remains.

Overall, the data suggest that the inundation was probably gentle, if that is possible. This statement is supported by the fine-grained nature of the deposits, the presence of quiet water species of foraminifera/ostracodes, and the mixed sizes of artifactual materials (small and large) found within any particular transect collection unit. This characterization is true at the Econfina Channel and J&J Hunt sites, but at the Fitch Site there was evidence for movement of artifacts sometime after full inundation. The effect of low-frequency, high-energy storm surges cannot be ignored in this case.

Virtually all of the artifacts encountered during our offshore forays were found in the upper (marine sand) stratigraphic unit. Artifacts tend to occur within bedrock outcrops, particularly in bedrock voids, which probably act as protective vessels for the items. Artifacts are unsorted throughout this matrix at J&J Hunt and Econfina, with artifact weights ranging from 0.1 g to more than 200 g within any particular sampling unit, suggesting replacement of terrestrial sediments and deflation of artifacts, but little lateral movement. Artifacts found nearer the sediment surface are brown in color and often exhibit corroded edges and growth of marine organisms, such as barnacles. Artifacts found at depth are often free of corrosion, although they sometimes exhibit a black (possible freshwater) patina. Some artifacts at the Econfina Channel Site exhibit extreme chemical corrosion (Faught, 1996). This corrosion can be accounted for by the "ionic strength effect," an increase in corrosiveness which occurs with the blending of fresh and salt waters in karst environments (Milanovic, 1981). This fact may also play a part in creating the numerous solution features in the limestone exposed along the modern coast and provides an analog for zones of karst fields offshore, such as the Econfina karst field (Figure 2).

Based on observation of nearshore aerial photographs, clusters of successive oyster bioherms in linear arrays extend at approximately regular intervals from the mouth of the modern Aucilla River, almost to the location of the J&J Hunt Site at 6.1 km offshore. Bioherms in shallower water exhibit living individuals, and those in deeper water are assumed to be completely relict. We suggest that these oyster bioherms formed progressively shoreward as sea levels rose, and that they represent potential sources of stratigraphic and radiocarbon data which could be used to reconstruct a detailed record of the inundation process (Faught, 1980). Similar results were obtained by Hine et al. (1988) in subsurface studies of the west Florida coast south of Crystal River.

Environmental conditions and sea levels similar to those of today are usually considered to have evolved by about 5000 yr B.P., but radiocarbon evidence from the mouth of Aucilla suggests that this actually occurred between 5000 and 4000 yr B.P. (Hoenstine and Garrett, 1993). Modern barrier island formation in the northeastern Gulf began approximately 3000 yr B.P. (Stapor et al., 1988).

While no direct evidence was observed regarding late Holocene high stands of sea level during the course of this research, the fragments of branching coral observed at both J&J Hunt and the Fitch Sites imply deeper water in the past. No living specimens of branching coral were observed at either site, which may represent secondary evidence for higher sea levels at some time during the Holocene.

CONCLUSIONS

Inundated archaeological sites are small targets to find in the great expanse of the continental margins. Visibility is often poor and sediment cover can preclude immediate recognition of archaeological sites or paleoterrestrial features. Purely random surveys of the continental shelf stand little chance of success in locating drowned cultural sites. In order to meet the needs of marine inundated, continental shelf archaeological research, methods need to be developed and practiced that can resolve this unique geoarchaeological problem.

Our experience has demonstrated that a focus on the discovery of submerged terrestrial features in areas with potentials for pre-5000 yr B.P. archaeological resources and relatively thin sediment cover yields good results. The use of terrestrial analogs to find archaeological sites rests on the assumption that sites will be found in geologic and topographic settings underwater which are similar to those found in nearby terrestrial areas. Most terrestrial analogs are of sufficient size to locate offshore with subbottom, bathymetric, or even direct visual survey. In terrestrial settings, sites are often found near fluvial and aquatic features, near lithic (chert) resources, and at the mouths of rivers in estuarine conditions. Therefore, these kinds of features can be located underwater by delineating the past drainage patterns of submerged river systems, by discovering buried karst features such as isolated sinkholes, by finding chert rock outcrops and by determining the locations of past sea-level stillstands and strandlines (Gagliano et al., 1982; Kraft et al., 1983).

A straightforward way to identify relict fluvial or other geomorphic features in any submerged area is by studying enhanced topographic mesh diagrams derived from detailed bathymetric maps, such as that shown in Figure 2. The topographic patterns reconstructed from the diagrams can reveal the trend of past drainage systems and other topographic irregularities that may reflect the locations of drowned terrestrial features such as river valleys, rock outcrops, and ledges or scarps. Initial study of the isobaths on the NOAA bathymetric map of the Apalachee Bay study area revealed a few potential areas for survey, one of which resulted in the discovery of Area A at the J&J Hunt site (Figures 6 and 7). However, the mesh diagrams generated by gridding and contouring analysis emphasized subtle nuances of topography which were more useful in identifying potential locations for diver surveys.

Subbottom profiler data represent an extremely useful means of discovering and reconstructing paleo-drainage systems and their sediment fill. Combined, subbottom profiler and bathymetric enhancement methods allow a much clearer picture of paleotopography and paleo-drainage configurations. By these means, this project revealed several specific areas which were revisited for detailed survey.

Direct diver observations by tow survey, hand fanning by divers, and sediment coring or dredge excavations are invaluable tools as the scale of inquiry becomes reduced and particular features or areas are targeted for further inquiry. Sediment covers ranging from 1 to perhaps 4 or 5 m are also manageable with the vibracoring and dredging methodology used in this research.

Prior to this investigation we assumed that the present-day discontinuous karst paleo-drainage system continued offshore for some distance. We might now ask how far out on the continental shelf does the karst plain continue and how might the transition from karst control to more alluvial control of drainage have affected human utilization and settlement of the region? Furthermore, how might this affect site locations, conditions, and site discovery techniques on the continental shelf? Could there be other, low-order karst drainage systems farther out on the shelf which drained into this paleo-Ochlockonee River and might these locales also exhibit datable evidence for the association of extinct fauna and humans in submerged sinkhole features?

In our research area artifacts found at shallow depths in the marine sediments are vertically disturbed, but perhaps no more so than for sites known from plow zones in terrestrial settings. The mix of artifact sizes is rich in many instances and implies little transport or sorting. Therefore, past behavioral and cultural data can still be gleaned from the careful analysis of the artifacts and their horizontal distributions. Given our increasing knowledge of the sediments and preservation potentials, discoveries of *in situ* archaeological materials can be expected with additional induction dredge exposures.

This research has established a foundation for further discoveries and investigations. Continued research, site discovery, and radiocarbon dating are necessary to resolve the full range of past Paleoindian and Archaic settlement patterns. Toward this goal we are convinced that we have located several potential sinkhole analogs of the terrestrial Page/Ladson Site in the discontinuous channel segment near the offshore J&J Hunt Site. Even though the 1992 excavations bottomed out on dolomite rubble in Test Pit 1, the probability that these clasts are diagenetic suggests that Paleoindian and extinct faunal remains could still exist below. Future research can examine these deeper stratigraphic sequences, survey the more distal reaches of the paleofluvial system, and search for more evidence for the colonization of the continent and the processes of submergence that obscures these remains.

This research would have not have been possible without the cooperation of various institutions, including Florida State University, the University of Florida, and the University of Arizona. Funding was provided by the Fitch Fund for Education (Texas Communities Foundation), a grant from the National Science Foundation (Grant No. BIN 9100515), and Earthwatch. Advice, encouragement, induction dredges, and other specialized equipment were offered by J. Miller of the Bureau of Archaeological Research, Florida Department of State, Tallahassee, D. Webb of the University of Florida, and V. Haynes of the University of Arizona. J. Dunbar, also of the Bureau of Archaeological Research, was instrumental in guiding the initial stages of the research and in identifying locations for survey. CAD mapping of subsurface features was carried out with the cooperation of J. Latvis. P. Gerrell and R. Anuskiewicz provided much advice and field assistance.

The exceptional people of the Florida State University Academic Dive Program, under the direction of G. Stanton, and those of the Florida State University Marine Labs, under the direction of J. Hitron, were all extremely cooperative. The subbottom profiler was provided by R. Floyd (John Chance and Associates), facilitated by R. Anuskiewicz of the Minerals Management Service (MMS). Radiocarbon dates were obtained from the University of Arizona accelerator lab; pollen was analyzed by B. Hansen, of The Pollen Connection, Stillwater, Minnesota. Foraminifera and ostracodes were inventoried by M. Palacios of the Department of Geology, University of Arizona. Thin section analysis of the dolomite was provided by T. Demko, Department of Geology, University of Arizona. Various members of the Florida Geological Survey, under the direction of R. Hoenstine, provided much helpful advice and suggestions. Z. Q. Chen drew the interpreted sections for the seismic figures.

From the beginning, this research has been accomplished through the efforts of professionals and nonprofessionals alike. Field crew members included J. Latvis, M. Stallings, R. Denson, and B. Carter, whereas local support came from J. and J. Hunt, J. Simpson, B. Page, S. Young, and R. Childress, among others. Our heartfelt gratitude goes out to all of these individuals. The manuscript was also considerably improved by reviews by D. Belknap and an anonymous reviewer, for which we are most grateful. This article is a contribution of the International Geological Correlation Program (IGCP) Project 367.

REFERENCES

Anderson, D.G. (1991). Examining Prehistoric Settlement Distribution in Eastern North America. *Archaeology of Eastern North America* **19,** 1–21.

Anderson, D.G., and Hanson, G.T. (1988). Early Archaic Settlement in the Southeastern United States: a Case Study from the Savannah River Valley. *American Antiquity* **53,** 262–286.

Anuskiewicz, R.J. (1988). Preliminary Archaeological Investigations at Ray Hole Spring in the Eastern Gulf of Mexico. *Florida Anthropologist* **41,** 181–185.

Anuskiewicz, R.J., Gerrell, P.R., Dunbar, J.S., and Donoghue, J.F. (1994). Evidence of Prehistoric Man on the North American Continental Shelf from a Sinkhole Located 32 Km. Offshore in 12 m Seawater. 59th Annual Meeting of the Society for American Archaeology, Anaheim, CA.

Back, R.M. (1972). Recent Depositional Environment of the Florida Middle Ground. Master's Thesis, Florida State University, Tallahassee.

Bailey, G., and Parkington, J. (1988). *The Archaeology of Prehistoric Coastlines.* Cambridge: Cambridge University Press.

Ballard, R.D., and Uchupi, E. (1970). Morphology and Quaternary History of the Continental Shelf of the Gulf Coast of the United States. *Bulletin of Marine Science* **20,** 547–559.

Beck, B.F. (1986). A Generalized Genetic Framework for the Development of Sinkholes and Karst in Florida, USA. *Environmental Geology and Water Science* **8,** 5–18.

Bergantino, R.N. (1971). Submarine Regional Geomorphology of the Gulf of Mexico. *Geological Society of America Bulletin* **82,** 741–752.

Bloom, A.L. (1983). Sea Level and Coastal Morphology of the United States Through the Late Wisconsin Glacial Maximum. *In* Porter, S.C., Ed., *Late Quaternary Environments of the United States, Volume 1, The Late Pleistocene,* pp. 215–229. Minneapolis: University of Minnesota Press.

Bokuniewicz, H. (1980). Groundwater Seepage into Great South Bay, New York. *Estuaries and Coastal Marine Science* **10,** 257–288.

Bonnichsen, R. (1991). Clovis Origins. *In* R. Bonnichsen and K.L. Turnmire, Eds., *Clovis: Origins and Adaptations,* pp. 309–329. Corvallis, Oregon: Center For the Study of the First Americans.

Brooks, G. (1981). Recent Carbonate Sediments of the Florida Middle Ground Reef System, Northeastern Gulf of Mexico. Master's Thesis, University of South Florida, St. Petersburg.

Brooks, M.J., Stone, P.A., Colquhoun, D.J., and Steele, K.B. (1986). Geoarchaeological Research in the Coastal Plain Portion of the Savannah River Valley. *Geoarchaeology* **1,** 293–307.

Bullen, R.P. (1975). *A Guide to the Identification of Florida Projectile Points.* Gainesville, Florida: Kendall Books.

Cable, J., Burnett, W., and Chanton, J. (in press) Magnitude and Variations of Groundwater Seepage Along a Marine Shoreline. *Biogeochemistry.*

Cline, R. (1981). *Seasonal Reconstruction of the Earth's Surface at the Last Glacial Maximum.* USGS Map MC-36. Reston, Virginia: U.S. Geological Survey.

Coastal Environments, Inc. (1977). Cultural Resources Evaluation of the Northern Gulf of Mexico Continental Shelf. Washington, D.C.: Interagency Archaeological Services, Office of Archaeology and Historic Preservation, National Park Service, U.S. Department of the Interior.

Colquhoun, D.J., and Brooks, M.J. (1986). New Evidence from the Southeastern U.S. for Eustatic Components in the Late Holocene Sea Levels. *Geoarchaeology* **1,** 275–291.

Colquhoun, D.J., Brooks, M.J., and Stone, P.A. (1995). Sea-Level Fluctuation: Emphasis on Temporal Correlations with Records from Areas with Strong Hydrologic Influences in the Southeastern United States. *Journal of Coastal Research, Special Issue* **17,** 191–196.

Continental Shelf Associates (1985). Florida Big Bend Seagrass Habitat Study: Narrative Report. OCS Study MMS 85-0088. New Orleans Environmental Studies Group, Gulf of Mexico Regional Office, MMS.

Coudray, J., and Montaggioni, L. (1986). The Diagenetic Products of Marine Carbonates as Sea-Level Indicators. *In* O. van de Plassche, Ed., *Sea-Level Research: A Manual for the Collection and Evaluation of Data,* pp. 311–360. Norwich, U.K.: Geobooks.

Curray, J.R. (1960). Sediments and History of Holocene Transgression, Continental Shelf Northwest Gulf of Mexico. *In* F.P. Shepard, F.B. Phleger, and T. van Andel, Eds., *Recent Sediments, Northwest Gulf of Mexico,* pp. 221–266. Tulsa, Oklahoma: American Association of Petroleum Geologists.

Daniel, R., and Wisenbaker, M. (1987). *Harney Flats: A Florida Paleo-Indian Site.* Farmingdale, New York: Baywood Publishing Co.

Daniel, I.R., Wisenbaker, M., and Ballo, G. (1986). The Organization of a Suwannee Technology: the View from Harney Flats. *Florida Anthropologist* **39,** 24–56.

Dixon, E.J. (1989). Reassessing the Occurrence and Survival of Submerged Terrestrial Archaeological Sites on the Bering Continental Shelf. *In* J.B. Arnold, Ed., *Underwater Archaeology—Proceedings from the Society for Historical Archaeology Conference.* Baltimore: Society for Historical Archaeology.

Donoghue, J.F. (1992). Late Quaternary Coastal and Inner Shelf Stratigraphy, Apalachicola Delta Region, Florida. *Sedimentary Geology* **80,** 293–304.

Donoghue, J.F. (1993). Late Wisconsinan and Holocene Depositional History, Northeastern Gulf of Mexico. *Marine Geology* **112,** 185–205.

Donoghue, J.F., and Tanner, W.F. (1992). Quaternary Terraces and Shorelines of the Panhandle Florida Region. *In* J.F. Wehmiller, and C.H. Fletcher, Eds., *Quaternary Coasts of the United States: Marine and Lacustrine Systems,* pp. 233–241. SEPM Special Publication 48. Tulsa: Society for Sedimentary Geology.

Donoghue, J.F., and White, N.M. (1994). Late Holocene Sea Level Change and Delta Migration, Apalachicola River Region, Northwest Florida, U.S.A. *Journal of Coastal Research* **11,** 651–663.

Donoghue, J.F., Demirpolat, S., and Tanner, W.F., (1990). Recent Shoreline Changes, Northeastern Gulf of Mexico. *Geological Society of America Abstracts with Programs* **22**(4), 11.

Donoghue, J.F., Anuskiewicz, R.J., Dunbar, J.S., Gerrell, P.R., and Faught, M. (1995). Evidence of Early Humans on the Northeastern Gulf of Mexico Continental Shelf: Ray Hole Spring. Abstracts, SEPM (Society for Sedimentary Geology) Congress on Sedimentary Geology, St. Pete Beach, Florida, August 13–16, p. 48.

Doyle, L.J., and Sparks, T.N. (1980). Sediments of the Mississippi, Alabama, and Florida, (MAFLA) Continental Shelf. *Journal of Sediment Petrology* **50,** 905–916.

Dunbar, J.S. (1991). Resource Orientation of Clovis and Suwannee Age Paleoindian Sites in Florida. *In* R. Bonnichsen and K.L. Turnmire, Eds., *Clovis: Origins and Adaptations,* pp. 185–214. Corvallis, Oregon: Center for the Study of the First Americans.

Dunbar, J.S., and Waller, B.I. (1983). A Distribution Analysis of the Clovis/Suwannee Paleo-Indian Sites of Florida—A Geographic Approach. *Florida Anthropologist* **36,** 18–30.

Dunbar, J.S., Webb, S.D., and Faught, M.K. (1988). Page/Ladson (8 Je 591): An Underwater Paleoindian Site in Northwestern Florida. *Florida Anthropologist* **41,** 442–452.

Dunbar, J.S., Webb, S.D., and Cring, D. (1989). Culturally and Naturally Modified Bones from a Paleoindian Site in the Aucilla River, North Florida. *In* R. Bonnichsen and M.H. Sorg, Eds., *Bone Modification,* pp. 473–497. Orono, Maine: Center for the Study of Early Man.

Dunbar, J.S., Webb, S.D., and Faught, M.K. (1992). Archaeological Sites in the Drowned Tertiary Karst Region of the Eastern Gulf of Mexico. *In* L. Johnson and M. Stright, Eds., *Paleo-Shorelines and Prehistory: An Investigation of Method,* pp. 117–146. Boca Raton, Florida: CRC Press.

Edwards, R.L., and Merrill, A.S. (1977). A Reconstruction of the Continental Shelf Areas of Eastern North America for the Times 9,500 B.P. and 12,500 B.P. *Archaeology of Eastern North America* **5,** 1–43.

Edwards, R.L., Beck, J.W., Burr, G.S., Donahue, D.J., Chappell, J.M.A., Bloom, A.L., Fruffel, E.R.M., and Taylor, F.W. (1993). A Large Drop in Atmospheric $^{14}C/^{12}C$ and Reduced Melting in the Younger Dryas, Documented with ^{230}Th Ages of Corals. *Science* **260,** 962–967.

Emery, K.O., and Edwards, R.L. (1966). Archaeological Potential of the Atlantic Continental Shelf. *American Antiquity* **31,** 733–737.

Emiliani, C., Rooth, C., and Stipp, J.J. (1978). The Late Wisconsin Flood in the Gulf of Mexico. *Earth and Planetary Science Letters* **41,** 159–162.

Evans, M.W., Hine, A.C., Belknap, D.F., and Davis, R.A. (1985). Bedrock Controls on Barrier Island Development: West-Central Florida Coast. *Marine Geology* **63,** 262–283.

Evans, M.W., Hine, A.C., and Belknap, D.F. (1989). Quaternary Stratigraphy of the Charlotte Harbor Estuarine/Lagoon System, Southwest Florida: Implications of the Carbonate-Siliciclastic Transition. *Marine Geology* **88,** 319–348.

Fairbanks, R.G. (1989). A 17,000-Year Glacio-Eustatic Sea Level Record: Influence of Glacial Melting Rates on the Younger Dryas Event and Deep-Ocean Circulation. *Nature* **342,** 637–642.

Faught, M.K. (1980). Better Than Tree Rings? *In* S.M. Lewenstein, Ed., *Proceedings of the Eighth International Congress for the Study of the Pre-Columbian Cultures of the Lesser Antilles* (pp. 214–217). Arizona State University Anthropological Research Papers No. 22. Tucson: Arizona State University.

Faught, M.K. (1988). Inundated Sites in the Apalachee Bay Area of the Eastern Gulf of Mexico. *Florida Anthropologist* **41,** 185–190.

Faught, M.K. (1989). Preliminary Report on the Excavation of the Econfina Channel Site: An Inundated Archaic Lithic Quarry in the Apalachee Bay, Florida. Open File Report. Tallahassee: Florida Bureau of Archaeological Research.

Faught, M.K. (1990). Report of the 1989 Offshore Field Session. Open File Report. Tallahassee: Florida Bureau of Archaeological Research.

Faught, M.K. (1992). Report of the 1991 Offshore Field Session: Discovery of Paleo-River Channel Sediments and Paleoindian Diagnostics on the Continental Shelf. Open File Report. Tallahassee: Florida Bureau of Archaeological Research.

Faught, M.K. (1996). Clovis Origins and Underwater Prehistoric Archaeology in Northwestern Florida. Ph.D. Dissertation, University of Arizona, Tucson.

Faught, M., and Donoghue, J.F. (1994). Inundated Archaeological Sites and Paleo-River Channels in the Apalachee Bay of Northwest Florida. 59th Annual Meeting of the Society for American Archaeology, Anaheim, California.

Faught, M.K., Anderson, D.G., and Gisiger, A. (1994). North American Paleoindian Database—An Update. *Current Research in the Pleistocene* **11,** 32–35.

Fernald, E.A., and Purdum, E.D., Eds. (1992). *Atlas of Florida.* Gainesville: University Press of Florida.

Field, M.E. (1974). Buried Strandline Deposits on the Central Florida Inner Continental Shelf. *Geological Society America Bulletin* **85,** 57–60.

Fladmark, K.R. (1979). Routes: Alternate Migration Corridors for Early Man in North America. *American Antiquity* **44,** 55–69.

Flemming, N.C. (1983). Survival of Submerged Lithic and Bronze Age Artifact Sites: A Review of Case Histories. *In* P.M. Masters and N.C. Flemming, Eds., *Quaternary Coastlines,* pp. 135–173. New York: Academic Press.

Frazier, D.E. (1974). Depositional Episodes: Their Relationship to the Quaternary Stratigraphic Framework in the Northwestern Portion of the Gulf Basin. Geological Circular 74-1. Austin, Texas: Bureau of Economic Geology.

Gagliano, S.M., Pearson, C.E., Weinstein, R.A., Wiseman, D.E., and McClendon, C.M. (1982). Sedimentary Studies of Prehistoric Archaeological Sites: Criteria for the Identification of Submerged Archaeological Sites of the Northern Gulf of Mexico Continental Shelf. Contract No. C35003(79). Washington, D.C.: U.S. Department of the Interior, National Park Service, Division of State Plans and Grants.

Garrett, S.E. (1983). Coastal Erosion and Archaeological Resources on National Wildlife Refuges in the Southeast. Atlanta: Archaeological Services Branch, NSP, Southeastern Region.

Garrison, E.G. (1992). Recent Archaeogeophysical Studies of Paleoshorelines of the Gulf of Mexico. *In* L.L. Johnson and M. Stright, Eds., *Paleoshorelines and Prehistory: An Investigation of Method,* pp. 103–116. Boca Raton, Florida: CRC Press.

Gifford, J.A. (1990). Analysis of Submarine Sediments off Paralia. *In* T.J. Wilkinson and S.T. Duhon, Eds., *Franchthi Paralia: The Sediments, Stratigraphy, and Offshore Investigations,* pp. 85–207. Bloomington: Indiana University Press.

Gleason, P.J., and Spackman, W. (1974). Calcareous Periphyton and Water Chemistry in the Everglades. *In* P.J. Gleason, Ed., *Environments of South Florida: Present and Past,* pp. 146–181. Memoir No. 2. Miami: Miami Geological Society.

Hicks, S.D. (1973). Trends and Variability of Yearly Mean Sea Level, 1893–1971. Technical Memorandum NOS 12. Rockville, Maryland: NOAA.

Hine, E.C., Belknap, D.F., Hutton, J.G., Osking, E.B., and Evans, M.W. (1988). Recent Geological History and Modern Sedimentary Processes along an Incipient, Low-Energy, Epicontinental Sea Coastline: Northwest Florida. *Journal of Sedimentary Petrology* **58,** 567–579.

Hoenstine, R., and Garrett, C. (1993). Coastal Wetlands Study: Annual Report for Year 1—Aucilla River. Open File Report. Tallahassee: Florida Geological Survey.

Holmes, N.H., and Trickey, B.E. (1974). Late Holocene Sea Level Oscillations in Mobile Bay. *American Antiquity* **39,** 122–124.

Hutton, J.G., Hine, A.C., Evans, M.W., Osking, E.B., and Belknap, D.F. (1984). Influence of a Karstified Limestone Surface on an Open-Marine, Marsh Dominated Coastline: West Central Florida. *In* B.F. Beck, Ed., *Sinkholes: Their Geology, Engineering and Environmental Impact,* pp. 35–42. Orlando: Florida Sinkhole Research Institute.

Johnson, L.L., and Stright, M.J., Eds. (1992). *Paleoshorelines and Prehistory: An Investigation of Method.* Boca Raton, Florida: CRC Press.

Jordan, G.F. (1952). Reef Formation in the Gulf of Mexico Off Apalachicola Bay, Florida. *Bulletin of the Geological Society of America* **63,** 741–744.

Jordan, G.F. (1954). Large Sink Holes in Straits of Florida. *Bulletin of the American Association of Petroleum Geologists* **38,** 1810–1817.

Kelly, R.L., and Todd, L.C. (1988). Coming into the Country: Early Paleoindian Hunting and Mobility. *American Antiquity* **53,** 231–244.

Kraft, J.C. (1986). Marine Environments: Paleogeographic Reconstructions in the Littoral Region. *In* J. Stein and W. Farrand, Eds., *Archaeological Sediments in Context,* pp. 111–125. Orono, Maine: Center for the Study of Early Man.

Kraft, J.E., Belknap, D.F., and Kayan, I. (1983). Potentials of Discovery of Human Occupation Sites on the Continental Shelves and Nearshore Coastal Zone. *In* P.M. Masters and N.C. Flemming, Eds., *Quaternary Coastlines and Marine Archaeology,* pp. 87–120. London: Academic Press.

Lanesky, D.E., Logan, B.W., Brown, R.G., and Hine, A.C. (1979). A New Approach to Portable Vibracoring Underwater and on Land. *Journal of Sedimentary Petrology* **49,** 654–657.

Leventer, A., Williams, D.F., and Kennett, J.P. (1982). Dynamics of the Laurentide Ice Sheet during the Last Deglaciation: Evidence from the Gulf of Mexico. *Earth and Planetary Science Letters* **59,** 11–17.

Masters, P.M., and Flemming, N.C. (1983). *Quaternary Coastlines and Marine Archaeology.* New York: Academic Press.

Milanich, J.T. (1994). *Archaeology of Precolumbian Florida.* Gainesville: University Press of Florida.

Milanovic, P.T. (1981). *Karst Hydrogeology.* Littleton: Water Resources Publications.

Moore, W.S. (1996). Large Groundwater Inputs to Coastal Waters Revealed by Ra-226 Enrichments. *Nature* **380,** 612–614.

Murphy, L.E. (1990). 8SL17: Natural Site-Formation Processes of a Multiple-Component Underwater Site in Florida. Submerged Cultural Resources Special Report, Professional Papers No. 39. Santa Fe, NM: Southwest Cultural Resources Center.

Neill, W.T. (1964). The Association of Suwannee Points and Extinct Animals in Florida. *Florida Anthropologist* **17,** 17–32.

Nelson, H.F., and Bray, E.E. (1970). Stratigraphy and History of the Holocene Sediments in the Sabine High Island Area, Gulf of Mexico. *In* J.P. Morgan, Ed., *Deltaic Sedimentation,* pp. 48–77. Tulsa, Oklahoma: Society of Economic Paleontologists and Mineralogists.

Opdyke, N.D., Spangler, D.P., Smith, D.L., Jones, D.S., and Lindquist, R.C. (1984). Origin of the Epeirogenic Uplift of Pliocene-Pleistocene Beach Ridges in Florida and Development of the Florida Karst. *Geology* **12,** 226–228.

Otvos, E.G. (1991). Northeastern Gulf Coast Quaternary. *In* R.B. Morrison, Ed., *Quaternary Non-glacial Geology of the Conterminus United States, Vol. K-2 of The Geology of North America,* pp. 588–594. Boulder, Colorado: Geological Society of America.

Pearson, C.E., Kelley, D.B., Weinstein, R.A., and Gagliano, S.M. (1986). Archaeological Investigations on the Outer Continental Shelf: A Study within the Sabine River Valley, Offshore Louisiana and Texas. Prepared for the U.S. Department of the Interior, Minerals Management Service. Reston, Virginia, Contract #14-12-0001-30072. Baton Rouge, Louisiana. Coastal Environments, Inc.

Pearson, C.E., Weinstein, R.A., and Kelley, D.B. (1989). Evaluation of Prehistoric Site Preservation on the Outer Continental Shelf: The Sabine River Area, Offshore Texas and Louisiana. *In* J.B. Arnold, Ed., *Underwater Archaeological Proceedings of the Society for Historical Archaeology Conference,* pp. 6–11. Baltimore: Society for Historical Archaeology.

Perlman, S.M. (1980). An Optimum Diet Model, Coastal Variability, and Hunter-Gatherer Behavior. *In* M.B. Schiffer, Ed., *Advances in Archaeological Method and Theory,* Vol. 3, pp. 257–309. New York: Academic Press.

Perlmutter, M.A. (1985). Deep Water Clastic Reservoirs in the Gulf of Mexico: A Depositional Model. *Geo-Marine Letters* **5,** 105–112.

Popenoe, P., Kohout, F.A., and Manheim, F.T. (1984). Seismic Reflection Studies of Sinkholes and Limestone Dissolution Features on the Northeastern Florida Shelf. *In* B.F. Beck, Ed., *Sinkholes: Their Geology, Engineering and Environmental Impact,* pp. 43–57. Orlando: Florida Sinkhole Research Institute.

Purdy, B.A. (1981). *Florida's Prehistoric Stone Technology: A Study of the Flintworking Technique of Early Florida Stone Implement Makers.* Gainesville: University Press of Florida.

Purdy, B.A. (1991). *The Art and Archaeology of Florida's Wetlands.* Boca Raton: CRC Press.

Rehkemper, L.J. (1969). Sedimentology of Holocene Estuarine Deposits, Galveston Bay. *In* R.R. Lankford and J.J.W. Rogers, Eds., *Holocene Geology of the Galveston Bay Area,* pp. 12–52. Houston, Texas: Houston Geological Society.

Richardson, S. (1988). Survey of the Aucilla River South From Ward Island on the Jefferson–Taylor County Line, Florida. *Florida Anthropologist* **41,** 471–482.

Rosenau, J.C., Faulkner, G.L., Hendry, C.W., and Hull, R.W. (1977). *Springs of Florida.* Bulletin 31 (rev.). Tallahassee: Florida Geological Survey.

Rupert, F., and Spencer, S. (1988). *Geology of Wakulla County, Florida.* Bulletin 60. Tallahassee: Florida Geological Survey.

Ruppe, R.J. (1980). The Archaeology of Drowned Terrestrial Sites: A Preliminary Report. *In* D.S. Brose, Ed., Coes Landing, Jackson County, Florida: a Fort Walton Campsite on the Apalachicola River, pp. 35–45. Bulletin No. 6. Tallahassee: Bureau of Historic Sites and Properties.

Russo, M., Purdy, B.A., Newsom, L.A., and McGee, R.M. (1992). A Reinterpretation of Late Archaic Adaptations in Central East Florida: Groves' Orange Midden (8 Vo 2601). *Southeastern Archaeology* **11,** 95–108.

Scholl, D.W., and Stuiver, M. (1967). Recent Submergence of Southern Florida: A Comparison with Adjacent Coasts and Eustatic Data. *Geological Society of America Bulletin* **78,** 437–454.

Scholl, D.W., Craighead, F.C., and Stuiver, M. (1969). Florida Submergence Curve Revisited: Its Relation to Coastal Sedimentation Rates. *Science* **163,** 562–564.

Schnable, J.E., and Goodell, H.G. (1968). *Pleistocene-Recent Stratigraphy, Evolution, and Development of the Apalachicoala Coast, Florida.* Special Paper No. 112. Boulder, Colorado: Geological Society of America. 72 p.

Serbousek, D. (1983). Explorations of a Paleo-Indian Site on the Aucilla River. *Florida Anthropologist* **36,** 88–97.

Serbousek, D. (1988). An Example of an Offshore Sinkhole in the Gulf of Mexico with Good Archaeological Potential. *Florida Anthropologist* **41,** 190–191.

Stanford, D. (1991). Clovis Origin and Adaptations: An Introductory Perspective. *In* R. Bonnichsen and K.L. Turnmire, Eds., *Clovis: Origins and Adaptations,* pp. 1–14. Corvallis, Oregon: Center for the Study of the First Americans.

Stapor, F.W., Mathews, T.D., and Lindfors-Kearns, F.E. (1988). Episodic Barrier Island Growth in Southwest Florida: A Response to Fluctuating Holocene Sea Level? *Miami Geological Society Memoir* **3,** 149–202.

Stapor, F.W., Mathews, T.D., and Lindfors-Kearns, F.E. (1991). Barrier-Island Progradation and Holocene Sea-Level History in Southwest Florida. *Journal of Coastal Research* **7,** 815–838.

Steeples, D.W., Knapp, R.W., and Miller, R.D. (1984). Examination of Sinkholes by Seismic Reflection. *In* B.F. Beck, Ed., *Sinkholes: Their Geology, Engineering and Environmental Impact,* pp. 217–223. Orlando: Florida Sinkhole Research Institute.

Stright, M.J. (1986a). Human Occupation of the Continental Shelf during the Late Pleistocene/Early Holocene: Methods for Site Location. *Geoarchaeology* **1,** 347–364.

Stright, M.J. (1986b). Evaluation of Archaeological Site Potential on the Gulf of Mexico Continental Shelf Using High Resolution Seismic Data. *Geophysics* **51,** 605–622.

Stright, M.J. (1990). *Archaeological Sites on the North American Continental Shelf.* Geological Society of America Centennial Special Volume 4, pp. 439–465. Boulder, Colorado: Geological Society of America.

Sullivan, A.P., and Rozen, K.C. (1985). Debitage Analysis and Archaeological Interpretation. *American Antiquity* **50,** 755–779.

Tanner, W.F. (1992). 3000 Years of Sea Level Change. *Bulletin of the American Meteorological Society* **73,** 297–303.

van den Bold, M.C., Moslow, T.F., and Coleman, J.M. (1987). Origin and Timing of Seafloor Erosion on the Louisiana Continental Slope. *Gulf Coast Association of Geological Societies Transactions* **37,** 487–498.

van de Plassche, O. (1986). *Sea-Level Research: A Manual for the Collection and Evaluation of Data.* Norwich, U.K.: Geo Books.

Walker, K.J., Stapor, F.W., and Marquardt, W.H. (1994). Episodic Sea Levels and Human Occupation at Southwest Florida's Wightman Site. *Florida Anthropologist* **47,** 161–179.

Waller, B. (1983). Florida Anthropologist Interview with Ben Waller. *Florida Anthropologist* **36,** 31–39.

Watts, W.A. (1971). Postglacial and Interglacial Vegetation History of Southern Georgia and Central Florida. *Ecology* **52,** 676–690.

Watts, W.A. (1983). Vegetational History of the Eastern U.S., 25,000–10,000 Years Ago. *In* S. Porter, Ed., *Late Quaternary History of the United States: Volume 1, The Pleistocene,* pp. 294–310., Minneapolis: University of Minnesota Press.

Watts, W.A., Hansen, B.C.S., and Grimm, E.C. (1992). Camel Lake: A 40,000 yr Record of Vegetational and Forest History from Northwest Florida. *Ecology* **73,** 1056–1066.

Webb, S.D., Milanich, J.T., Alexon, R., and Dunbar, J.S. (1984). A Bison Antiquius Kill Site, Wacissa River, Jefferson County, Florida. *American Antiquity* **49,** 384–392.

Widmer, R.J. (1988). *The Evolution of the Calusa.* Tuscaloosa: University of Alabama Press.

Willis, C. (1988). Controlled Surface Collection of the Little River Rapids Site (8Je603): A Stratigraphically Deflated Site in the Aucilla River, North Florida. *Florida Anthropologist* **41,** 453–470.

Received April 22, 1996
Accepted for publication February 25, 1997