Fossil diatoms (Bacillariophyta) as potential paleoenvironmental indicators at St. Catherines Island, Georgia.

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Contents

Abstract

In this research we identify diatoms contained in the guts of three living, filter-feeding mollusks that are commonly identified in the shell middens of St. Catherines Island, Georgia, USA: Eastern Oyster (*Crassostrea virginica*); hard clam (*Mercenaria* sp.); and Atlantic ribbed mussel (*Geukensia demissa*). These taxa, along with water samples were collected during each season between 2009 -2010 from two locations on St. Catherines Island. The resulting modern assemblage of diatoms forms a comparative collection that might be expected to be identified in St. Catherines Island archeological sites. Thirty-six sediment samples were excavated and evaluated for their palynological content. Diatom recovery from archeological samples collected from two shell midden sites on St. Catherines Island, Georgia was poor, probably due to the alkaline nature of the shell midden sediments. Diatoms, if recovered from areas outside the shell middens, where the sediment pH is more acidic, may provide the assemblages needed to reconstruct paleoenvironmental conditions at the time of midden formation. Recovery of diatoms and other microorganisms as pollen, spores, and fungal elements from the gut contents of three taxa of living shellfish provides a systematic treatment and description of 27 diatoms which represent the first recorded and systematically described diatoms from the coastal waters of Georgia. These descriptions may facilitate the identification of fossil diatoms recovered from sediments associated with shell middens elsewhere on the island.

Key words: Palynology; archaeology; diatoms; pollen; spores; mollusca; St. Catherines Island; Georgia

Introduction

"Salt marshes…are glorious places, bugs and all. With their green and brown grasses producing nutrients for the sea, they are among the richest places and most productive environments on earth. Able to withstand salt water, the grasses stand eternally as a buffer between the murky estuaries and bays and the high green forests, exuding life and energy. – Jack Rudloe, *The Wilderness Coast*, 1988

The salt marshes surrounding the islands of the coast of southeastern United States harbor a rich and diverse biota. In these waters are contained an assemblage of planktonic and benthic organisms, key of which are the diatoms. Diatoms (Bacillariophyta) are single-celled benthic or planktonic algae that form durable, biogenic silica cell walls (frustules). There are about 200 genera and more than 100,000 species of diatoms worldwide (Round et al., 1990). The frustule shape and morphological details may be used to identify genera or species in recent habitats and subrecent lithological deposits (Round et al., 1990). The diatoms represent a poorly understood resource in the field of environmental archaeology and paleobiology along the Georgia Coast, and the study of extant diatoms along the Atlantic and Gulf Coasts of Florida and Georgia are for the most part, non-existent (Evelyn Gaiser, written communication, 2008). Diatoms, having specific salinity and pH requirements, may be useful in reconstructing paleohabitats represented in the shell middens found on St. Catherines Island (Vos and Wolf, 1993; Stoermer and Smol, 1999).

Shell middens are anthropogenic deposits that account for nearly 5000 years of human and environmental history of St. Catherines Island. The zooarchaeological record

indicates that shellfish have been part of the subsistence base for at least the last five millennia along the United States southeastern coast (Thomas, 2008, p. 979). Many of the bivalves and gastropods that comprise shell middens are suspension feeders that occupy intertidal to shallow subtidal zones where they consume diatoms (and other microorganisms) as they filter feed. Mollusks were collected as food resources where their shells and some soft tissue were discarded as midden fill. During this process some of the mollusk gut content containing diatoms may have been deposited into the middens. This report investigates the feasibility of recovering and using diatoms as environmental proxies of St. Catherines Island shell middens. This study also contributes to the paleobiological research that has been addressing St. Catherines Island environmental change (Thomas, 2008).

St. Catherines Island has been inhabited for at least 4000 years, possibly more, and was a Guale settlement by 1576. It was the northernmost permanent Spanish outpost on the Atlantic coast in 1587. During the 17th century, the mission of Santa Catalina de Guale on St. Catherines Island was the center of the Guale missionary province of Spanish Florida (Thomas, 1988). Today the island is privately owned by the Edward John Noble Foundation (New York) and serves as a research base for scientists concerned with the fauna, flora, anthropology and paleobiology of the island.

Methods and Materials

The island of St. Catherines is located several miles off the Atlantic coast of Georgia in Liberty County, Georgia, at 31° 37’ N latitude and 81° 09’ W longitude (Text-figure 1). It lies approximately 50 miles (80 km) south of Savannah, Georgia. The island is ten miles (16 km) long and from one to three miles (1.6 to 4.8 km) wide; more than

half of its 14,640 acres (59 km²) are tidal marsh and wetlands, reached only by boat. Extant shellfish specimens of three genera from the east and west sides of the island were collected during all seasons, as modern comparative specimens. Subrecent fossil and soil samples were collected from the St. Catherines shell midden and McQueen shell midden sites on the island.

Collection and processing of extant shellfish

Collections of living, filter-feeding mollusks that are commonly identified in the shell middens of St. Catherines Island were made from the island on four separate occasions to represent the four seasons of the year. At each season, four specimens each of the Eastern oyster [*Crassostrea virginica* (Gmelin 1791)], hard clam (*Mercenaria* spp.) and, Atlantic ribbed mussel [*Geukensia demissa* (Dillwyn 1817)] were collected. Collections from the East side of the island (Atlantic Ocean side) and from the West side of the island (landward side) were made of each of the three shellfish taxa. A water sample was also collected from each site, to record pH and salinity (Table I) and to concentrate the planktonic organisms from which a comparative slide was prepared. The West Side locality is at the South End Dock area (GPS N 31° 36.403' W 081° 10.646') along an adjacent stream bottom. The East Side locality is at the Kings New Ground site (GPS N 31° 38.519' W 081° 09.206'), along a stream channel (Text-figure 2). The collection dates for the extant comparative specimens were August 18, 2009 (summer), November 14, 2009 (autumn), February 21, 2010 (winter), and April 24, 2010 (spring).

The diatom flora contained within the gut contents of these mollusks serves as a comparative collection for both sides of the island through the four seasons of the year.

The stomach contents of the recent shellfish specimens were dissected from surrounding tissues, placed in a numbered series of 100 ml glass beakers, covered with a 5% solution of KOH (potassium hydroxide) and left to stand overnight (Text-figure 3).

The contents of the 100 ml beakers were transferred to a numbered series of conical bottom, 15 ml centrifuge tubes for processing. Processing included three washes in distilled water to remove the KOH. Each wash was followed by centrifugation to concentrate the diatoms and other organic material. The supernatant was poured off and optically checked for content. Once it was determined that the supernatant was free of organic material, it was discarded. The remaining slurry was then sieved through a 10 μm sieve to remove fine particulate, inorganic material. The slurry was at this stage halved, the two fractions receiving different treatments. One half was washed in distilled water three times and once in 90% ethanol, as a prelude to slide preparation. The second half was treated with acetolysis mixture (one part sulfuric acid *into* nine parts acetic anhydride) and warmed in a hot bath at 90° C for 7 to 10 minutes. Following the acetolysis treatment (Erdtman, 1960), the sample was washed three times in distilled water and once in 100% ethanol. Slides, to be used as comparative material, were prepared using Permount™ as a mounting medium. Permount has a refractive index (R.I.) of 1.55, providing good contrast with the diatom frustules which have a R.I. of about 1.43. The cover slips were sealed with clear nail polish (Sally Hanson *Hard as Nails*™).

Identification of extant and subrecent diatoms were made using several sources including Round et al. (2007), Tomas (1996), Patrick and Reimer (1966, 1975), Suthers

and Rissik (2009), and through discussions with M. J. Sullivan (St. Andrews Episcopal School, Ridgeland, MS).

Collection and processing of fossil/subrecent samples

Thirty-six subrecent samples were collected by Matt Sanger from two archeological sites previously excavated (Text-figure 4) by the American Museum of Natural History (AMNH), Division of Anthropology (Thomas, 2008). Ten (10) soil samples were collected from the AMNH Site 504 (= St. Catherines Shell Ring, south wall feature). Eighteen (18) samples of loosely consolidated soil and shell material were collected from AMNH 504, T281 (= St. Catherines Shell Ring, north wall of trench 281), and eight (8), carbonaceous, shell and soil samples were collected from AMNH 696 (= McQueens Shell Ring, east wall). All samples were collected on May 27, 2009, and transported to the Florida Museum of Natural History (FLMNH), Paleobotany and Palynology Laboratory for processing. Table 2 provides the sample collection data.

Processing of the subrecent soil and shell midden samples followed for the most part standard palynological processing techniques as outlined by Bryant (2009) and Jarzen (2006). The use of hydrofluoric acid (HF) was omitted in order to retrieve the siliceous frustules of the diatom flora. As a result of not using HF to remove the silicates, the resulting residue is often laden with crystals of silica making observation and photography difficult. Two slides were prepared for each residue fraction using Glycerin jelly, Cellosize™ and Lucite™ or Cellosize and Permount™ as the mounting media (medium noted on slide label). Pollen and spores are better observed and photographed

using either glycerin jelly or Lucite as the mounting medium, while diatoms fare better using Permount. The cover slips were sealed with clear nail polish (Sally Hanson *Hard as Nails*™). Slides of both extant comparative material and subrecent archaeological samples, and the remaining residues and unused sediment samples, are curated at the Paleobotany and Palynology Laboratory, FLMNH, Gainesville, Florida, 32611, USA as Localities UF 19272, UF 19273, and UF 19274. Access to these collections may be made through Dr. Hongshan Wang (hwang@flmnh.ufl.edu).

Photographs of the palynomorphs (diatoms, algal cysts, pollen, spores, etc.) were made using a Nikon Coolpix 4500™ camera mounted on a Leitz Dialux 20™ research microscope. Specimens are located by stage coordinates marking an x (horizontal) and y (vertical) axis (with printed label to the left), location for the Leitz Dialux 20 microscope (Serial Number 513467). Specimens may also be located using the England Finder Slide locator. For details of the nature and instructions for use of the England Finder Slide, see: (http://www.2spi.com/catalog/magnifiers/england-finder-graticule-instructions.html.)

Diatom Systematics

"*Taxonomy (the science of classification) is often undervalued as a glorified form of filing—with each species in its folder, like a stamp in its prescribed place in an album; but taxonomy is a fundamental and dynamic science, dedicated to exploring the causes of relationships and similarities among organisms. Classifications are theories about the basis of natural order, not dull catalogues compiled only to avoid chaos."*
Stephen Jay Gould, *Wonderful Life* (1989, p. 98)

The systematic section covers the palynomorphs (any organism or part thereof including pollen, spores, diatoms, silicoflagellates, or other organic material) recovered

from the living shellfish and water samples. The diatom classification follows that of Round, Crawford and Mann (2007).

Division Bacillariophyta

Class Coscinodiscophyceae

Order Thalassiosirales

Family Skeletonemaceae

Skeletonema R.K. Greville 1865

Skeletonema costatum (Greville) Cleve 1878

Plate 3, figure 1

Features: Cells joined into elongate chains, forming filaments, appearing as “beads” joined by thin “threads”. The “threads” are really fine striations running along the long axis of the chain.

Habitat: Common in the coastal marine plankton.

Remarks: Zingone et al. (2005) and Sarno et al. (2007) have examined the type material of *Skeletonema*, and defined the phylogenetic position and diversity within the genus.

Family Stephanodiscaceae

Cyclotella F.T. Kützing ex A. de Brébisson 1838

Cyclotella sp.

Plate 1, figure 2

Features: Cells solitary, circular in valve view, drum shaped. Sometimes forming filaments, chains or clusters (Round et al., 1990).

Habitat: Mainly freshwater, but invading brackish coastal waters (Round et al., 1990). This form was common in the water samples and most of the gut samples.

Remarks: Prasad and Nienow (2006) discuss and describe the centric diatom genus *Cyclotella* from the Florida Bay region. The genus has about 100 species. A similar genus is *Stephanodiscus* which differs from *Cyclotella* in lacking a distinct ring of spines as seen in valve view (Round et al., 1990).

Order Melosirales

Family Melosiraceae

Melosira C.A. Agardh 1824

Melosira sp.

(not illustrated)

Features: Cells are cylindrical, to subspherical and united in chains or filaments.

Habitat: Common in marine and freshwater epibenthic (living on the surface of sediment) habitats. *Melosira* was rarely found in the water and mollusk gut samples collected from St. Catherines Island.

Remarks: *Melosira* prefers, though not restricted to, olighaline water, or waters with low salinity (0.5 to 5.0 ppt). Hasle and Syvertsen (1996) discuss the distribution and identification of species of *Melosira*.

Order Paraliales

Family Paraliaceae

Paralia P.A.C. Heiberg 1863

Paralia marina (W. Smith) Heiberg.

Plate 1, figure 7

Features: Cells are cylindrical, united to form linked chains of several cells. Those observed here are free, circular in valve view, giving the impression in valve view of a "toothed gear." Diameter of the valve is variable from 8 – 130 µm (Tomas, 1996).

Habitat: Common on near shore plankton, especially on sandy sediments. The genus is common in many of the gut samples collected from St. Catherines Island (see Tables 4 and 5).

Remarks: This is a small genus of only two (possibly three) species, *P. marina* and the fossil taxon, *P. sulcata* (Round et. al., 2007). A detailed account of the genus may be found in Crawford (1979).

Order Coscinodiscales

Family Coscinodiscaceae

Coscinodiscus C.G. Ehrenberg 1838

Coscinodiscus sp.

Plate 1, figures 3, 4; Plate 2, figure 2

Features: Centric, discoid, thin to thicker and more barrel-shaped.

Habitat: Marine free living in the plankton. Common in coastal bays and estuaries. Common in the St. Catherines material.

Remarks: This genus has many species. Some of which have a documented fossil record (Round et al., 1990).

Family Hemidiscaceae

Actinocyclus C.G. Ehrenberg 1837

Actinocyclus sp.

Plate 2, figure 1

Features: The centric cells are barrel-shaped. The “pseudonodulus” is characteristic of the genus. This feature, a small pore-like structure, is often difficult to observe. The diameter of the frustrule ranges from 25 to 95 μm.

Habitat: Mostly epiphytic on seagrass (e.g. *Thalassia*), but also found in the nearshore plankton and in localities with mangroves.

Remarks: The pseudonodulus is often very difficult to observe under light microscopy (personal communication M. J. Sullivan, 2009)

Hemidiscus G.C. Wallich 1860

Hemidiscus sp.

Plate 3, figure 2

Features: Valves are cuneiforme (wedge shaped). Surface covered with closely spaced areolae.

Habitat: Widely distributed in marine warmer waters, carried to temperate waters on ocean currents.

Remarks: There are nine species within the genus. Blooms of *Hemidiscus* spp. are reported as the casual agent in mass mortality of fish and invertebrates in some areas (Subramanian and Purushothaman, 1985).

Family Heliopeltaceae

Actinoptychus C.G. Ehrenberg 1843

Actinoptychus sp.

Plate 1, figure 1

Features: Solitary, centric diatoms, cells circular in valve view. The valve is sectioned into six segments (but may be up to 20 segments), as in the slices of a pie. These sections alternate in height, providing an undulate surface.

Habitat: This diatom is common in neritic assemblages, free or attached to other algae on coastal sediments (Round et al., 1990).

Remarks: There may be as many as 150 validly published species (Round et al., 1990), making identification to the species level difficult for the non-specialist.

Order Triceratiales

Family Triceratiaceae

Odontella C.A. Agardh 1832

Odontella aurita (Lyngbye) C. A. Agardh

Plate 3, figure 3

Features: Solitary cells, oblong in girdle view, ornamented with elongated spines or apical elevations Cells may be united in chains.

Habitat: Marine planktonic or epiphytic, abundant in all ocean waters (Round et al., 1990).

Remarks: *Odontella* is a diatom monitored among toxic algae blooms by NOAA's Phytoplankton Monitoring Network (http://odontella.blogspot.com/).

Odontella mobiliensis (J. W. Bailey) Grunow

Plate 3, figure 4

Features: Solitary or in chains. Cells large ranging from 60 to 130 μm longest dimension (Johnson and Allen, 2005).

Habitat: Common in marine waters, preferring higher salinities.

Remarks: Species of *Odontella* are most abundant in north temperate regions, but are truly a cosmopolitan taxon.

Order Biddulphiales

Family Biddulphiaceae

Trigonium P.T. Cleave 1868

Trigonium sp.

Plate 2, figure 5

Features: Cells triangular in valve view, rectangular in girdle view. Occurring singly or in chains. Surface of cells pitted.

Habitat: A cosmopolitan, marine form attached to seagrasses.

Remarks: This form has a fossil record extending from the Late Eocene to the present (Round et al., 1990; Lautour, 1889)

Order Cymatosirales

Family Cymatosiraceae

Cymatosira A. Grunow 1862

Cymatosira belgica Grunow

(not illustrated)

Features: Valves rectangular to pointed, united in chains by interlocking teeth. The valves are heterovalvar, i.e. having slightly different morphology, especially at the ends of the valves.

Habitat: Marine benthic. Occurs in the episammon, sandy beaches and salt marshes (Round et al., 1990).

Remarks: Seen only rarely in the water samples.

Order Chaetocerotales

Family Chaetocerotaceae

Chaetoceros C.G. Ehrenberg 1844

Chaetoceros sp.

Plate 3, figure 5

Features: Cells rarely occur singly, mostly in chains, curved or coiled filaments, of a few to many cells. Each cell provided with elongated processes (setae), which serve to unite the cells. The setae may be up to several micrometers in length.

Habitat: A dominant form in marine waters, with a few forms found in fresh water.

Remarks: Rines and Hargraves (1988) have studied extensively the *Chaetoceros* of Narragansett Bay, Rhode Island.

Bacteriastrum G. Shadbolt 1854

Bacteriastrum sp.

Plate 3, figure 6

Features: Cells cylindrical, united in chains, each cell with several long, radiating, bifurcating, processes.

Habitat: Marine plankton, widely distributed.

Remarks: Round et al. (1990) note that *Bacteriastrun* is always associated with *Chaetoceros* spp. See Tables 4 and 5 for confirmation of this observation in the gut samples of the shellfish collected at St. Catherines Island.

Class Fragilariophyceae

Order Fragilariales

Family Fragilariaceae

Tabularia (Kützing) D.M. Williams & F. E. Round 1986

Tabularia sp.

(not illustrated)

Features: Cells elongate or “needle-like”, with tapered, rounded ends.

Habitat: World-wide marine to brackish water epiphytic and epilithic genus of diatoms.

Remarks: Very similar morphology to the freshwater genus *Synedra*. Only observed in the water samples, not in the gut samples collected from St. Catherines Island.

Order Rhaphoneidales

Family Rhaphoneidaceae

Rhaphoneis C.G. Ehrenberg 1844

Rhaphoneis sp.

Plate 1, figures 5,6; Plate 2, figure 3

Features: Cells usually solitary. Broadly elliptical in valve view, with rounded, pointed ends. Surface with closely spaced, aligned areolae.

Habitat: Common with a wide distribution in shallow marine habitats. Often found on sand grains (Round et al., 1990)

Remarks: This taxon has an excellent fossil record (Andrews, 1975).

Delphineis G. W. Andrews 1977

Delphineis surirella (Ehrenberg) G. W. Andrews

(not illustrated)

Features: Cell morphology similar to *Rhaphoneis*, but differs in the arrangement of the areolae.

Habitat: Episammon (sandy substrate) marine environments.

Remarks: This genus has an extensive fossil record (Round et al., 1990)

Family Thalassionemataceae

Thalassionema A. Grunow ex F. Hustedt 1932 *in* Rabenhorst

Thalassionema nitzschioides (Grunow) Grunow ex Hustedt

(not illustrated)

Features: Individual cells are linear elongated, forming zigzag, or stellate colonies. Size 2-3.5 µm wide, by 10-80 µm long.

Habitat: A common form found in the marine plankton.

Remarks: This is a small genus of only three species (Round et al., 1990).

Class Bacillariophyceae

Order Naviculales

Family Diploneidaceae

Diploneis C.G. Ehrenberg ex Cleve. 1894

Diploneis sp.

Plate 1, figure 10

Features: Cells peanut-shaped in valve view. Rounded elliptical with a midway, or nearly midway, constriction. Valves linear to elliptical with broadly rounded apices. Thickened canals are present on either side of the raphe slit and usually have a pattern of ornamentation that differs from the marginal striae (often seen as longitudinal lines either side of the axial area). Cells often robust in appearance (See: Linkletter, 1977).

Habitat: Mostly a marine form, but with a few freshwater forms.

Remarks: Diploneis is a common inhabitant of the supratidal area, tidal levees and in pools in the back levee marshes which are periodically dry (Vos and de Wolf, 1988)

Family Naviculaceae

Navicula J.B. M. Bory de St.-Vincent 1822

Navicula sp.

Plate 3, figure 7

Features: Cells solitary, naviculoid (boat-shaped), often narrow, elongated.

Habitat: Extremely common forms in freshwater and marine waters, cosmopolitan. Usually living on or in fine muddy sediments (epipelon).

Remarks: The genus is a large one, inasmuch as it has become a “dump” for many bilaterally symmetrical, raphid diatoms whose morphological details are difficult to discern. Patrick and Reimer (1966) have provided a comprehensive systematic treatment of the genus *Navicula* of the United States. There are several forms in the

water and gut samples collected from St. Catherines Island. Identification to species of the many forms observed, will require the work of a specialist.

Family Pleurosigmataceae

Pleurosigma W. Smith 1852

Pleurosigma sp.

Plate 3, figure 11

Features: Cells solitary, valves sigmoid, elongate, narrow. Surface with very fine small, areolae. This taxon may obtain large sizes, up to 300 μm (Tomas, 1996).

Habitat: Usually marine to brackish waters, on sand or planktonic. Sometimes in freshwater.

Remarks: A large genus of perhaps as many as 250 species (Tomas, 1996). The most common species, distributed from the tropics to the polar oceans is *P. normanii* as a part of the plankton.

Gyrosigma Hassall. 1845

Gyrosigma fasciola (Ehrenberg) J.W. Griffith & Henfrey

(not illustrated)

Features: Cells solitary, sigmoid in valve view. Similar to *Pleurosigma*, but differs in the structure of the areolae, which is difficult to observe using light microscopy.

Habitat: Common in brackish habitats, but extending into the marine environment (Round et al., 1990). A few species are commonly found in freshwater.

Remarks: Stidolph (1994) studied the genus and described the salient features of the frustrule in great detail.

Order Bacillariales

Family Bacillariaceae

Psammodictyon D. G. Mann 1990

Psammodictyon panduriforme (W. Gregory) D. G. Mann

var. *continua*

(not illustrated)

Features: Cells solitary, peanut-shaped in valve view, pointed to rounded ends.

Habitat: Marine epipelic form, widespread on sandy substrates.

Remarks: Sullivan (1977) reported the occurrence of this species (as *Nitzschia panduriformis* var. *continua*) associated with the grass *Spartina alterniflora* Loisel. From the Bay St. Louis, Mississippi. Rare in the St. Catherines samples.

Tryblionella W. Smith 1853

Trylbionella apiculata Gregory

Plate 3, figure 8

Features: Cells solitary, usually observed in valve view. Valves linear, slightly constricted centrally, bluntly rounded with ends terminating in a rounded point. Surface with parallel, closely spaced striations running perpendicular to the long axis.

Habitat: A large epipelic genus, but not too common in brackish and marine sediments.

Remarks: Also common in high-conductivity fresh water. The genus is close to *Psammodictyon* and *Nitzschia* (Round et al., 1990)

Tryblionella sp. cf. *T. gracilis* W. Smith

(not illustrated)

Features: Cells solitary, usually observed in valve view. Valves linear, slightly constricted centrally, bluntly rounded with ends terminating in a rounded point. Surface with parallel, closely spaced striations running perpendicular to the long axis.

Habitat: A large epipelic genus, but not too common in brackish and marine sediments.

Remarks: The identification of this species is tentative as the differences between this and the previous species are at best minor.

Nitzschia Hassall 1845

Nitzschia aurariae Cholnoky

Plate 3, figure 10

Features: Cells usually solitary, but sometimes linked into chains or stellate colonies. Frustules elongated, linear, with rounded tips. Striate surface, striae running perpendicular to the long axis. Surface between striae pitted.

Habitat: The many species of this genus are marine to freshwater in distribution, and common as epipelic or planktonic (Round et al., 1990)

Remarks: Round et al. (1990) note that *Nitzschia* is a large and difficult genus, that has been split into several sections by some workers. There are probably several species of *Nitzschia* present in the St. Catherines material, separation of which is beyond the scope of this report.

Nitzschia sigma (Kützing) W. Smith

(not illustrated)

Features: Cells usually solitary, but sometimes linked into chains or stellate colonies. Frustules elongated, linear, with rounded tips. Striate surface, striae running perpendicular to the long axis. Surface between striae pitted

Habitat: Marine to freshwater.

Remarks: See comments for *N. aurariae,* above.

Other Palynomorphs

In addition to the diatoms recovered from the shellfish gut contents and water samples, several other palynomorphs were recovered and identified. These include microforaminiferal test linings (Plate 2, fig. 12). These amoeboid protists are marine, free-floating plankton that form mineralized multi-chambered tests which rain down on the sediment in great numbers and are ingested by shellfish. Mathison and Chmura (1995) have demonstrated the value of using microforaminiferal test linings in the determination of salinity zones.

Fungal spores (Plate 1, fig. 14) and fructifications were recovered from nearly all samples from the three sites. Identification of the dispersed spores is frequently difficult, as many spores are only known through proper identification of their associated host organism. The work of Kalgutkar and Jansonius (2000) may be used to identify some of the spores or other fungal structures recovered. Further, more detailed work, by a trained mycologist, may allow for more identifications and environmental interpretations (See for example the work of Jarzen and Elsik, 1986) .

The Silicoflagellates *Dictyocha fibula* Ehrenberg was frequently encountered in the scanning of the shellfish gut contents slides. This amoeboid, flagellate organism is common in the upper water layers in all oceans and saltwater regions. The structure seen in Plate 1, fig. 8 is the inner, silicate, skeleton of the living organism.

Phytoliths (Plate 1, fig. 15) are silicate-based inorganic structures recovered in the shellfish gut contents. They are the result of biological processes within the cells of some higher angiosperms (notably palms and grasses) which deposit silica in a soluble state absorbed from groundwater within and between plant cells (Piperno, 2006). After death of the plant, the phytoliths may be released into the surrounding water (as is the case for aquatic plants) or into the sediments (as is the case for terrestrial plants).

Pollen grains (Plate 1, figs. 11-13 and Plate 2, figs. 6-11) recovered from the three sites include pollen of *Pinus* (perhaps several species of pine), *Quercus* (oak), *Carya glabra* (Pignut hickory), Gramineae (grass family), *Myrica*-type (probably wax myrtle), *Alnus* (Alder), Chenopodium/Amaranthaceae-type, Compositae (aster family), *Juniperus virginiana* L. (Red Cedar), *Liquidambar styraciflua* L. (Sweet gum), and several as yet undetermined tricolpate and tricolporate angiosperm pollen types. All of the identified pollen forms represent plants that occur on St. Catherines Island (Cole and Jones, 1988), and are a part of the “pollen rain” flora.

Trilete and monolete spores were recovered from the shellfish gut contents. Cole and Jones (1988) list only six pteridophytes as growing on the island, although it is possible that the spores recovered from the gut contents were transported from the mainland, and represent taxa not listed by Cole and Jones (1988).

Further identification of the pollen and spores collected from the gut contents of the shellfish, especially the numerous tricolporate forms, will require detailed study and possibly the use of scanning electron microscopy (SEM).

Results and Conclusions

The 36 archaeological samples collected from three sites (AMNH 504, AMNH 504, T281, and AMNH 696) on St. Catherines Island, Georgia, were barren of diatoms and pollen. Sparse fungal spores are present, and plant tissue is abundant indicating that the processing techniques, especially the oxidation methods used were not responsible for the barren nature of the samples. It is suggested that the alkalinity of the shell middens is responsible for the lack of palynomorphs. Dimbleby (1995) has noted that the pH of sediments is critical for the preservation of palynomorphs, especially pollen and spores.

Diatoms are composed of biogenic silica (BSi, hydrated silica, $SiO_2 \bullet nH_2O$), which is comparable to opal and amorphous opaline silica. BSi is essential to the growth and functions of many plants and animals. Flower (1993) has discussed the preservation and disolution of living and fossil diatoms. The process is a complex one that involves chemical processes, the details of which are beyond the scope of this report. Basically biogenic silica is easily disolved in alkaline sediments. Inasmuch as the middens, and indeed the samples processed for this experiment, were largely composed of shell fragments the pH would be, as expected, more alkaline than acidic.

Even though the midden samples proved barren of identifiable organic remains, this report serves another, arguably scientifically valuable purpose. The diatoms and other microorganisms recovered from the gut contents of three taxa of living shellfish,

intended to serve as a comparison assemblage for the diatoms recovered from the archaeological sites, are within themselves a unique systematic collection. These diatoms collected from the gut contents of the Eastern oyster (*Crassostrea virginica*), the hard clam (*Mercenaria* spp.) and, Atlantic ribbed mussel (*Geukensia demissa*), from both sides of St. Catherines Island, during the four seasons of the year, provide the first documented, seasonal, diatom flora from the coastal waters of Georgia. Although perhaps somewhat incomplete and preliminary, these data, documented in the systematic section and in Tables 4 and 5, may be useful in the determination of seasonal variations in the feeding habits of the shellfish, and the seasonal diversity of the diatom species identified.

A total of 27 diatom taxa were identified from the gut samples. This number is certainly preliminary as identification of species and even genera requires the expertise of specialists. We were fortunate to have a diatomist, Dr. Michael Sullivan, assist us in the early stages of the identification of some of the taxa. Sullivan noted that more detailed study of the samples, both water and the gut content samples would be needed to fully understand the diatom flora at St. Catherines Island. With this caveat in mind, this report will treat only the 27 taxa thus far identified.

A cursory examination of Tables 4 and 5, will quickly indicate that some diatom species recovered from the water sample are rarely or never recovered from the gut samples of the three shellfish during any season of the year. This is no doubt a real absence and not a sampling or identification error as this absence is consistent. Note for example the absence of *Gyrosigma fasciula, Hemidiscus, Melosira, Skeletonema costatum, Tabularia* and *Thalasionema*. The significance of these absences is unknown to us, yet, may in part be due to selective filtering by the three shellfish species. This

selective filtering has been shown to be of significance in some shellfish. Cognie et al. (2001) have documented the selective feeding of the oyster, *Crassostrea gigas* (Pacific Oyster) on microbenthic organisms from estuarine environments at Bourgneuf Bay, France. These authors showed that under natural conditions four species of diatoms accounted for 95% of the diet of the oysters. Although detailed counts were not recorded for the various taxa recovered from the gut contents of *Crassostrea virginica* or from the other shellfish species investigated from St. Catherines Island, it was observed that certain diatom species were more abundant than others in these samples. Among the most frequently occurring diatoms are species of *Cyclotella* , *Coscinodiscus*, *Actinocyclus* and *Actinotycus*.

The near barren nature of the gut contents of *Crassostrea* and *Mercenaria* from the Summer 2009 collection from both the East and West sides of the island may in part be due to the as yet untested processing techniques employed during the early stages of this project. As the collection and processing techniques of the gut contents became routine, the recovery results improved. Future studies looking at the gut contents of shellfish should refine the processing techniques on test samples before the actual study begins. This lack of diatoms during this time of the year may also in part be due to the salinity of the water. Fritz, et al. (1999) have show that for saline lakes, the diversity and abundance of diatoms decreases with increased salinity. They were able to use fossil diatom assemblages to estimate the salinity range for ancient saline lakes. This however does not hold for the salinity of the waters around St. Catherines Island, as Table 1 clearly shows and increase in salinity later in the year and not necessarily during the summer of 2009. Increases in diatom diversity are not here linked to increases in

salinity. Salinity factors change with tides, rainfall and runoff, human activity, and time of day, so conclusions about salinity and diatom abundance are premature for this study.

Suggestions for Further Research

1. Work with professional diatom expert(s) to confirm or emend the identifications supplied in this report. This diatomist may also add additional taxa not observed or identified herein.
2. Recollect additional palynological samples inside and outside the shell ring deposits. Record soil pH at these collection sites. If possible invite a trained palynologist to assist in the collection of these samples. The amount and nature of the samples needed for palynological analysis varies from locality to locality and by sediment type. The amount of sample needed will also depend on several factors, prime of which is the type of sediment being collected and the nature of the kinds of palynomorphs being investigated.
3. Reprocess using preparation techniques not employed in this analysis, but following those of Bryant and Hall (1993) and Charles Stapleton as provided in Appendix I. These alternative processing techniques may provide final residues with better recovery of various palynomorphs. No one technique is better than all others.
4. Experimentation with various mounting media including Hyrax™, Arodor™, Naphrax™ and Pleurax™. These mounting media, specially manufactured with high refractive indices, may improve the optical properties of the diatoms thereby improving the photographic results (Hanna, 1930; Hanna, Penn and Ruedrich, 1929; Flemming, 1943, 1954).

5. Counts of all diatoms through all seasons, for the east and west localities should be made in order to determine the relative percentages of each taxon recovered. This may indicate the feeding preferences for selected shellfish during the year at each location. See: Cognie et al. (2001). With these counts various statistical methods could be employed to determine the significance of the presence or absence of species, species dominance, and recurrent species groups of the diatom species identified.
6. These data may be used to evaluate and supplement data obtained from geophysical samples already collected from the island.

The potential exists for several studies to complement the present work. Can diatoms be used to indicate past environmental conditions? The answer is obviously yes, pending the adequate recovery of material from ancient human occupied sites, and the proper processing and identification of the material. This report offers a beginning that may allow further research to fully understand the important role of diatoms as indicators of past environments and the nature of early, human, site occupation.

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midden samples. Our friend, Dr. Fred Rich (Georgia Southern University), offered advice on techniques and supplied published papers relevant to the palynology of St. Catherines Island. Professor Vaughn Bryant (Texas A&M University) likewise supplied advice on processing procedures, and provided valuable literature sources. Mr. Charles Stapleton, III (University of South Alabama), shared his unpublished diatom processing procedures with us for which we thank him. We especially wish to thank Dr. Michael J. Sullivan (St. Andrews Episcopal School, Ridgeland, MS) for his consul and identification of many of the diatoms recovered from the gut samples and water samples we studied. David Hurst Thomas (American Museum of Natural History) was instrumental in supplying literature sources, samples and discussions from which we and this report have benefitted.

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APPENDIX I

Processing of Diatoms using the methods of
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Approximately 1 teaspoon of sodium pyrophosphate was added to each jar (fill with water) to ensure disaggregation of the clumps of sediment. The samples sat for twenty four hours on a hot pad (rubber lab hot pads) with occasional swirling. Siphon down to ~200ml using a siphon tube (see below). H_2O_2 (~200 ml) (I used Claroxide™-40% which I got at a beauty supply store for a couple of dollars for 750ml) was added to each jar. Water was added to approximately one half (~500 ml) the jar. The jars were placed on a heating pad and swirled occasionally for at least 48 hours to ensure the removal of all organic material.

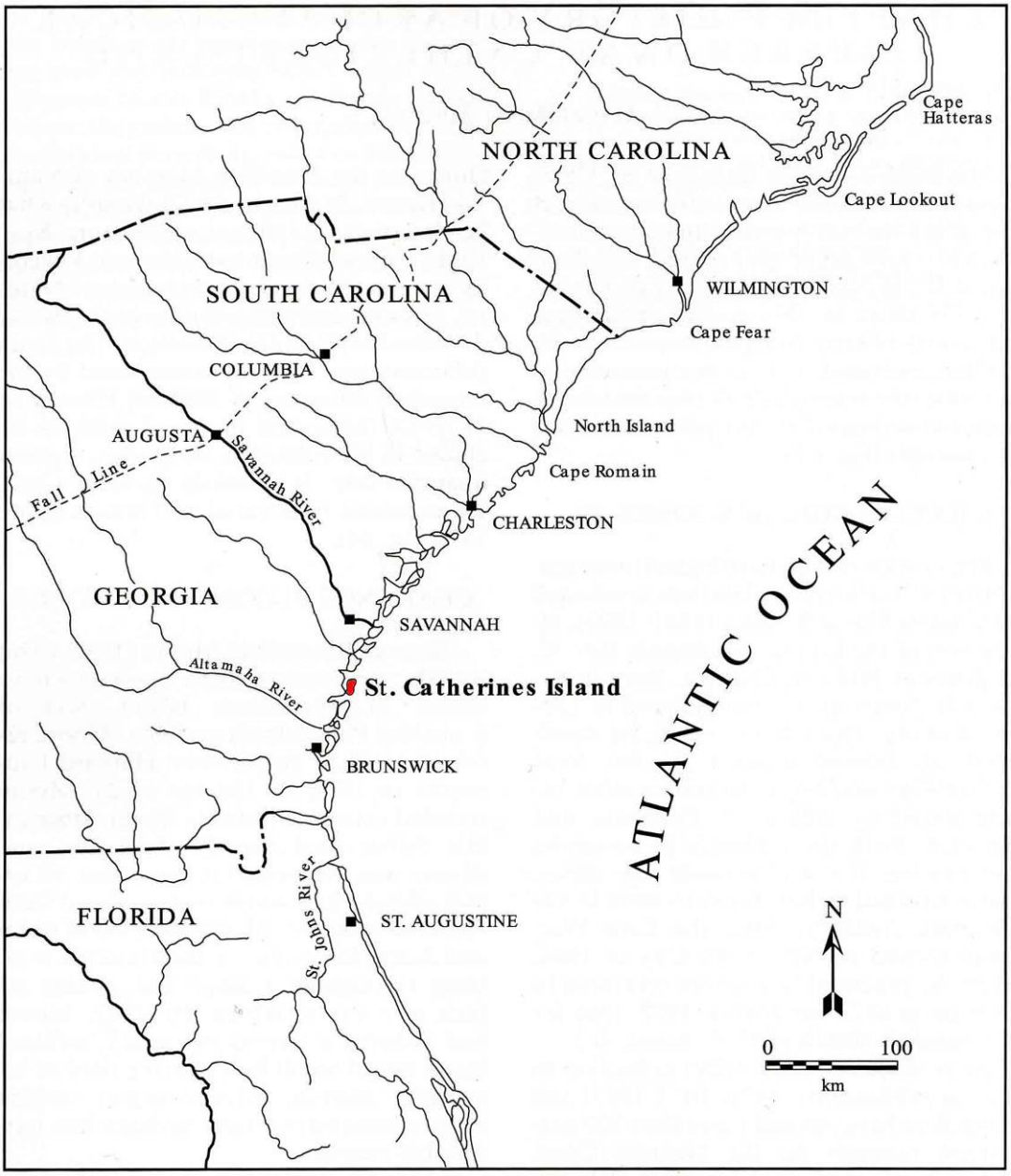
The samples were subjected to a lengthy settling procedure to remove clay particles. The jars were filled to a certain mark (~ 750ml) and after three hours were siphoned down to approximately 2 cm (~200 ml) above the settled sediment. Siphon with a 3/8 inch clear plastic tubing with a portion of the wide end of a glass disposable pipette inserted in the tube to decrease the siphon's vacuum effect. Repeat until the water above the sediment is clear (usually 10 to 12 iterations).

The sediment was transferred to 50cc test tubes as follows: Jars were swirled and a portion of the contents were decanted into test tubes. After two hours for settling, excess water in the tubes was siphoned (use ¼ inch flexible clear plastic tubing with a glass disposable pipette with approx 1cm of the thin portion of the pipette remaining) down to 50cc/ml. Ensure enough water is left over the sediment to prevent the siphon

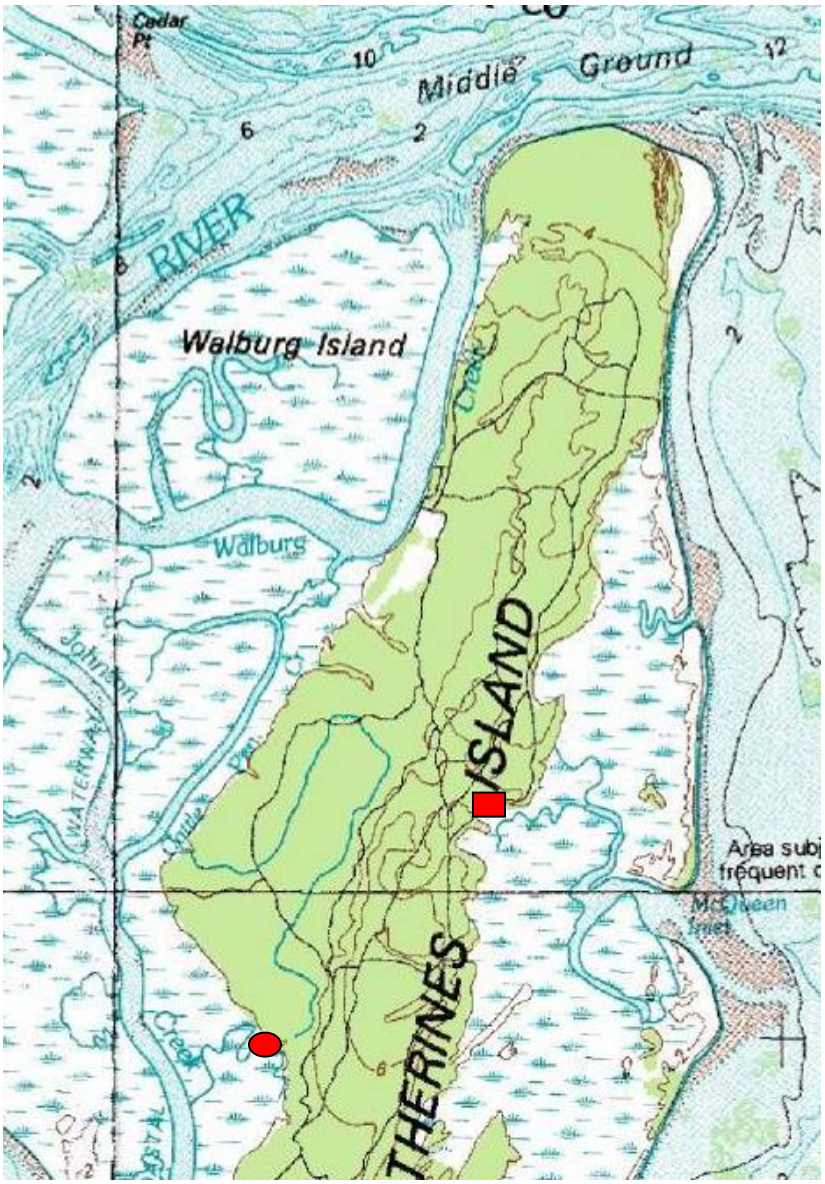
from sucking up sediment. Approximately, four iterations will be necessary to transfer the contents of the jars into the test tubes. Test tubes were centrifuged for approximately ten minutes at lower speeds and all excess water decanted.

Five ml of heavy liquid ($Zn\ Br_2$ with a specific gravity of 2.3) was added and the samples were mixed with a vortex mixer. At this specific gravity biogenic silica (including diatoms) float while the clastic silica sinks. The mixture was centrifuged for five minutes at higher speeds and the biogenic silica decanted into a clean tube. This procedure was repeated to ensure all biogenic silica was removed from the sample. Water was added to the $ZnBr_2$/biogenic silica mixture to reduce the specific gravity, which causes the biogenic silica to sink. The $ZnBr_2$ was recycled by filtration and re-concentration. The biogenic silica was “washed” (using the above settling method in the test tube) with distilled water until all $ZnBr_2$ was removed.

Slide preparation: Water was added to the samples until a certain level of opacity was achieved (approximately ¾ of the tube). Sub-samples were transferred to cover-slips with disposable pipettes. The cover-slips were covered with the water/sample and allowed to dry overnight before mounting on a slide using Naphrax™.



Text-figure 1. Map of the United States eastern seaboard showing location of St. Catherines Island (red) off the coast of Georgia.



Text-figure 2. Map of St. Catherines Island showing location of recent sample collection sites. Red circle indicates location of the South Dock site. Red square indicates the location of the McQueens inlet site.

Text-figure 3. Collecting and extracting gut content samples for palynological processing. A. Collecting hard clams from the McQueen Locality. B. Opening an Atlantic ribbed mussel shell. C. Hard clam body before dissection of gut contents. D. Gut contents of hard clam placed in glass beaker, ready for chemical treatment.

Text-figure 4. Location of AMNH locality sites. Red open circle indicates the location of the St. Catherines Ring. The open square indicates the location of the McQueen Shell Ring. These localities were collected for subrecent samples by Matt Sanger.

Table I. pH and salinity (parts per thousand), of water samples from the East side and West side of St. Catherines Island, GA, for the four seasons (2009 – 2010) . pH recorded at 23-24° C.

	SUMMER 08/18/2009	AUTUMN 11/14/2009	WINTER 02/21/2010	SPRING 04/26/2010
EAST	pH 6.8 / 32 ppt	pH 6.8 / 36 ppt	pH 6.2 / 30 ppt	pH 6.5/ 31 ppt
WEST	pH 6.4 / 30 ppt	pH 7.2 / 35 ppt	pH 6.1/ 25 ppt	pH 6.3/ 29 ppt

Table 2. Alphabetical listing of the taxa identified from the living shellfish and water samples collected from St. Catherines Island, Georgia, 2009 – 2010.

Actinocyclus C.G. Ehrenberg 1837
Actinoptychus C.G. Ehrenberg 1843
Bacteriastrum G. Shadbolt 1854
Chaetoceros C.G. Ehrenberg 1844
Coscinodiscus C.G. Ehrenberg 1840
Cyclotella Kützing ex Brébisson 1838
Cymatosira beligica Grunow in van Heurck 1880-1885
Delphineis surirella (Ehrenberg) G.W. Andrews 1977
Diploneis C.G. Ehrenberg ex Cleve 1894
Gyrosigma fasciula (Ehrenberg) J.W. Griffith & Henfrey 1856
Hemidiscus G.C. Wallich 1860
Melosira C.A. Agardh 1824
Navicula Bory de St.-Vincent 1822
Nitzschia Hassall 1845
Nitzschia sigma (Kützing) W. Smith 1853
Odontella aurita (Lyngbye) C.A. Agardh 1832
Odontella mobiliensis (J.W. Bailey) Grunow 1884
Paralia marina (W. Smith) Heiberg 1863
Pleurosigma W. Smith 1852
Psamimodictyon panduriforme(Gregory) Mann in Round, Crawford & Mann 1990
Rhaphoneis C.G. Ehrenberg 1844
Skeletonema costatum (Greville) Cleve 1878
Tabularia (Kützing) Williams & Round 1986
Thalasionema nitschioides (Grunow) van Heurck 1896
Trigonum Cleve 1867
Trybionella apiculata Gregory 1857
Tryblionella gracilis W. Smith 1853

Table 3. Collection data for the archaeological samples collected from St. Catherines Island, GA. The UF number is the accessioned locality at the Florida Museum of Natural History, University of Florida, Gainesville, Florida, U.S.A. AMNH LOC. Is the American Museum of Natural History original field number. The collector Matt Sanger was based at the AMNH at the time of the collections. UTM is the Universal Transverse Mercator coordinate location system.

LOCALITY	AMNH LOC.	NAME	NO. SAMP.	COLL/DATE
UF 19272	504	St. Catherines Shell Ring South Wall	10	Sanger 27/05/2009
UF 19273	504 T281	St. Catherines Shell Ring North Wall	18	Sanger 27/05/2009
UF 19274	696	McQueens Shell Ring	8	Sanger 27/05/2009

Table 4. Distribution of the diatom taxa identified in the shellfish gut contents through the four season of the year for the WEST side of St. Catherines Island. SUM = summer, AUT = autumn, WIN = winter, SPR = spring. 1 = *Crassostrea virginica*, 2 = *Mercenaria* spp., 3 = *Geukensia demissa*. For those taxa not showing a presence (+) through any of the four seasons, are taxa recorded only in the water samples and not recovered from the gut contents (e.g. *Gyrosigma fasciula*).

TAXON	SUM			AUT			WIN			SPR		
	1	2	3	1	2	3	1	2	3	1	2	3
Actinocyclus		+		+	+	+	+		+			
Actinoptychus			+		+	+	+	+	+			+
Bacteriastrum				+			+		+			
Chaetoceros				+			+		+			
Coscinodiscus		+	+		+	+	+	+	+	+	+	+
Cyclotella	+		+	+	+	+	+	+	+	+	+	+
Cymatosira beligica			+	+								
Delphineis surirella			+									
Diploneis				+		+				+		+
Gyrosigma fasciula												
Hemidiscus												
Melosira												
Navicula			+	+	+		+	+		+	+	+
Nitzschia							+				+	
Nitzschia sigma									+			
Odontella aurita					+							
Odontella mobiliensis							+					
Paralia marina					+				+	+		+
Pleurosigma				+			+					
Psamimodictyon panduriforme												
Rhaphoneis			+			+	+		+	+		+
Skeletonema costatum												
Tabularia												
Thalasionema nitschioides												
Trigonum			+						+		+	+
Trybionella apiculata				+	+			+		+	+	+
Tryblionella gracilis				+	+							+

Table 5. Distribution of the diatom taxa identified in the shellfish gut contents through the four season of the year for the EAST side of St. Catherines Island. SUM = summer, AUT = autumn, WIN = winter, SPR = spring. 1 = *Crassostrea virginica*, 2 = *Mercenaria* spp., 3 = *Geukensia demissa*. For those taxa not showing a presence (+) through any of the four seasons, are taxa recorded only in the water samples and not recovered from the gut contents (e.g. *Gyrosigma fasciula*).

TAXON	SUM			AUT			WIN			SPR		
	1	2	3	1	2	3	1	2	3	1	2	3
Actinocyclus			+	+	+		+			+		
Actinoptychus	+	+		+	+		+	+	+	+	+	
Bacteriastrum							+					
Chaetoceros							+			+		
Coscinodiscus			+	+	+		+		+	+	+	+
Cyclotella		+		+	+		+	+	+	+	+	+
Cymatosira beligica					+							
Delphineis surirella							+					
Diploneis			+	+	+		+	+		+		+
Gyrosigma fasciula												
Hemidiscus												
Melosira												
Navicula	+	+	+	+	+		+		+	+	+	+
Nitzschia						+				+		
Nitzschia sigma												
Odontella aurita												
Odontella mobiliensis												
Paralia marina		+			+		+	+	+	+		+
Pleurosigma						+		+		+	+	
Psamimodictyon panduriforme												
Rhaphoneis		+			+		+	+	+	+	+	
Skeletonema costatum												
Tabularia												
Thalasionema nitschioides												
Trigonum					+		+	+			+	
Trybionella apiculata				+			+	+	+	+	+	+
Tryblionella gracilis				+	+			+			+	

Plate 1. Selected palynomorphs including diatoms, pollen and fungal elements from the gut contents of shellfish collected from the South Dock (WEST) locality at St. Catherines Island, Georgia. These palynomorphs represent a cross section of the total palynoflora identified, and are representative of the gut contents of the Atlantic ribbed mussel (*Geukensia demissa*) collected in the Summer (SUM) of 2009. Slide location, England Finder Slide coordinates and dimensions are given for each entry.

1. *Actinoptychus* sp. Slide SUM, C-1, 25.3 x 102.1, EFS N25/3, diameter 42 μm.

2. *Cyclotella* sp. Slide SUM, C-1, 25.7 x 94.8, EFS V25, diameter 53 μm.

3. *Cosciodiscus* sp. Slide SUM, C-1, 28.2 x 109.9, EFS E28, diameter 34 μm.

4. *Cosciodiscus* sp. Slide SUM, C-2, 26.0 x 104.3, EFS L26/3, diameter 72 μm.

5. *Rhaphneis* sp. Slide SUM, C-2, 25.8 x 96.9, EFS T25/2, long axis 48 μm.

6. *Rhaphneis* sp. Slide SUM, C-2, 28.0 x 106.1, EFS J28, long axis 45 μm.

7. *Paralia marina.* Slide SUM, C-1, 33.8 x 96.1, EFS U34/1, diameter 27 μm.

8. *Dictyocha fibula.* Slide SUM, C-1, 30.6 x 99.5, EFS Q30/4, longest dimension 50 μm.

9. Centric diatom in girdle view. Slide SUM, C-1, 32.9 x 106.7, EFS J33/1, diameter 30 μm.

10. *Diploneis gruendleria.* Slide SUM, C-2, 25.7 x 95.0, EFS V25/2, long axis 53 μm.

11. *Pinus* sp. pollen. Slide SUM, C-2, 31.5 x 107.1, EFS H32/3, largest dimension 72 μm.

12. Tricolpate pollen grain. Slide SUM, C-1, 33.7 x 103.3, EFS M34/3, diameter 34 μm.

13. Gramineae (Poaceae) pollen, note single pore. Slide SUM, C-2, 27.7 x 104.2, EFS L27/4, diameter 42 μm.

14. Fungal, dicellate spore. Slide SUM, C-1, 37.2 x 108.0, EFS G37/4, long axis 19 μm.

15. Phytolith. Slide SUM, C-2, 35.5 x 107.6, EFS H36/1, long axis 30 μm.

PLATE 1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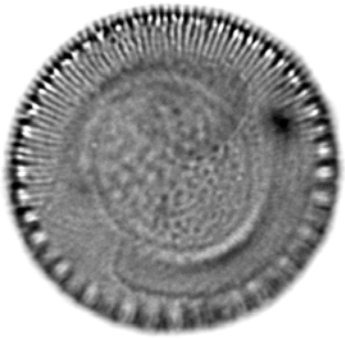
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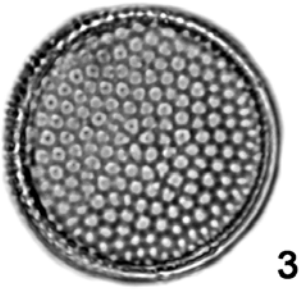
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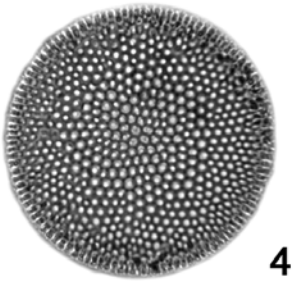
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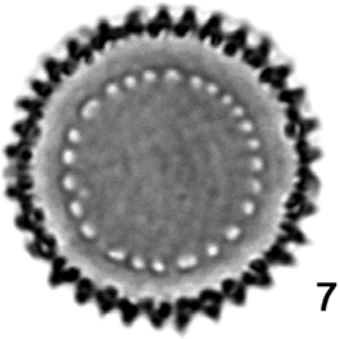
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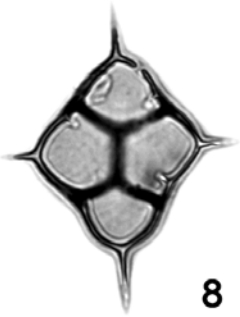
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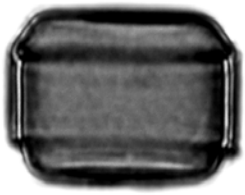
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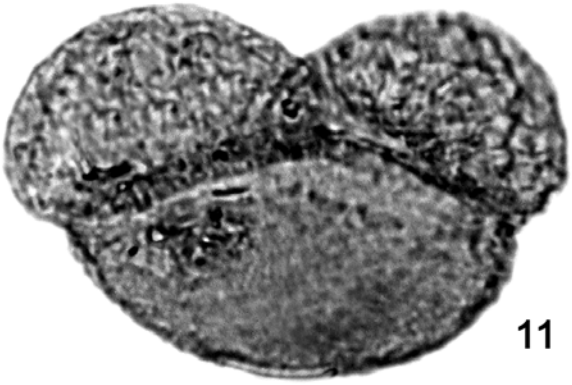
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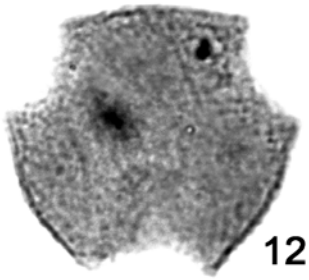
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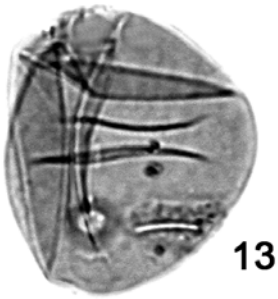
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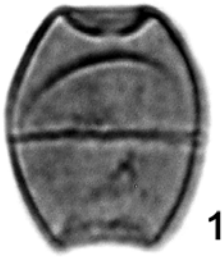
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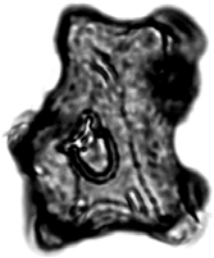
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Plate 2. Selected palynomorphs including diatoms and pollen from the gut contents of shellfish collected from the McQueens Inlet (EAST) locality at St. Catherines Island, Georgia. These palynomorphs represent a cross section of the total palynoflora identified, and are representative of the gut contents of the Eastern oyster (*Crassostrea virginica*) or Hard clam (*Mercenaria* spp.) collected in the Autumn (AUT) of 2009. Slide location, England Finder Slide coordinates and dimensions are given for each entry.

1. *Actinocyclus* sp. in *Crassostrea virginica.* Slide AUT, A-1, 23.1 x 105.4, EFS K23, diameter 53 μm.
2. *Coscinodiscus* sp. in *Crassostrea virginica.* Slide AUT, A-1, 25.2 x 100.0, EFS Q25/1, diameter 61μm.
3. *Rhaphoneis* sp. in *Crassostrea virginica.* Slide AUT, A-1, 32.2 x 100.1, EFS P32/4, long axis 60 μm.

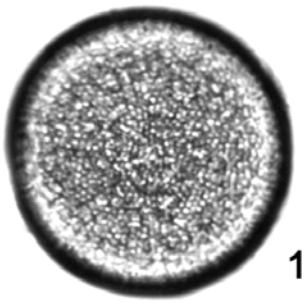
4a. Pennate diatom (probably *Navicula* sp.) in *Crassostrea virginica.* Slide AUT, A-1, 26.7 x 99.1, EFS Q37/3 long axis 76x μm.

4b. As above in different focal plane.

5. *Trigonium* sp. in *Mercenaria* sp. Slide AUT, A-1, 33.2 x 105.9, EFS J33/4, longest dimension 110 μm.
6. *Quercus* pollen in *Mercenaria* sp. Slide AUT, A-1, 27.3 x 111.0, EFS E27, diameter 21μm.
7. *Myrica* sp. in *Mercenaria* sp. Slide AUT, A-1, 30.1 x 103.9, EFS M30/2, diameter 30.5 μm.
8. Unknown spore (algal?) in *Crassostrea virginica.* Slide AUT, A-1, 32.4 x 106.8, EFS J32/2, diameter 61μm.
9. Periporate pollen (possibly Chenopodiaceae) in *Mercenaria* sp. Slide AUT, A-1, 34.8 x 101.2, EFS O35/3, diameter 23 μm.

10. *Carya* sp. pollen in *Mercenaria* sp. Slide AUT, A-1, 41.4 x 94.3, EFS W42/1, diameter 50 μm.
11. *Pinus* sp. pollen in *Mercenaria* sp. Slide AUT, A-1, 26.1 x 108.2, EFS G26, long axis 85 μm.
12. Miroforaminifera test lining in *Mercenaria* sp. Slide AUT, A-1, 33.1 x 97.7, EFS S33, diameter 65 μm.

PLATE 2



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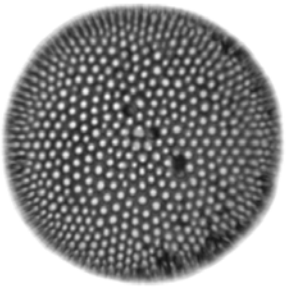

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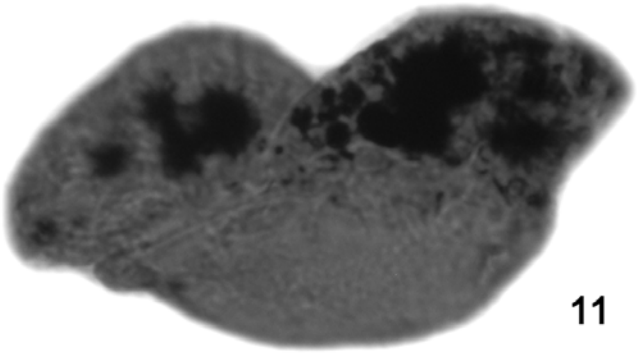

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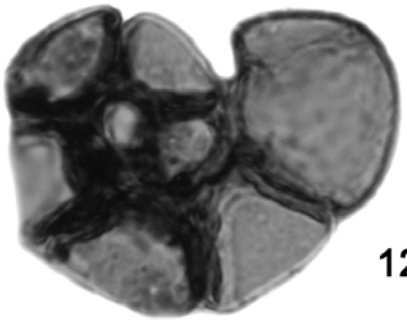

12

Plate 3. Selected diatoms from the water samples (WS) collected from the McQueens Inlet (EAST) and South Dock (WEST) localities at St. Catherines Island, Georgia. Slide location, England Finder Slide coordinates and dimensions are given for each entry.

1. *Skeletonema costatum* (chain of several cells). WS EAST, Summer, A-1, 23.1 x 95.3, EFS U23/3, length 135 μm.
2. *Hemidiscus sp.* WS WEST, Summer, A-1, 27.1 x 100.4, EFS P27, length 106 μm.
3. *Odontella aurita.* WS WEST, Summer, A-1, 20.1 x 108.7, EFS G20/1, long axis 34 μm.
4. *Odontella mobiliensis.* WS WEST, Summer, A-1, 25.3 x 97.0, EFS T25/2, long axis 225 μm.
5. *Chaetoceros* sp. WS EAST, Summer, A-1, 31.7 x 94.9, EFS V32/1, overall size about 100 μm.
6. *Bacteriastrum* sp. WS EAST, Summer, A-1, 24.7 x 107.4, EFS H24/2, diameter 60 μm.
7. *Navicula* sp. WS WEST, Autumn, A-1, 32.3 x 101.1, EFS O32/4, Long axis 76 μm.
8. *Tryblionella granulate.* WS EAST, Summer, A-1 32.7 x 107.0, EFS H33/3, long axis 38 μm.
9. *Rhaphoneis* sp. WS EAST, Summer, A-1 32.5 x 94.1, EFS W32/2, long axis 59 μm .
10. *Nitzschia scalpaliformis.* WS EAST, Summer, A-1, 27.4 x 106.1, EFS J27/4, Long axis 230 μm .
11. *Pleurosigma* sp. WS WEST, Autumn, A-1, 22.3 x 98.1, EFS S22/1, long axis 115 μm.

PLATE 3