Southeastern Geological Society
Annual Field Trip Guidebook

February 19-20, 1988
SOUTHEASTERN GEOLOGICAL SOCIETY

ANNUAL FIELD TRIP

AND

DINNER MEETING

GUIDEBOOK

FEBRUARY 19 & 20, 1988

COMPILED AND EDITED

BY

FREDRIC L. PIRKLE

AND

JOHN G. REYNOLDS
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Starke, Florida

Other Individuals Contributing to the Field Trip
R. A. Beale
Associated Minerals (USA)
Green Cove Springs, Florida

D. S. Jones
Florida State Museum
Gainesville, Florida

R. C. Lindquist
University of Florida
Gainesville, Florida

E. A. Mallard
E. I. Du Pont
Starke, Florida

T. M. Scott
Florida Geological Survey
Tallahassee, Florida

W. Smith
Florida Rock Industries, Inc., Grandin, Florida
ACKNOWLEDGMENTS

Deep appreciation is extended to E. I. Du Pont de Nemours and Company, Inc. for physical and financial support of this field conference. Also, thanks are extended to Associated Minerals (USA), Container Corporation of America, Parran Properties, Inc. and Florida Rock Industries, Inc. for their support of the conference and for granting permission for field trip participants to examine operations and exposures on their properties. Gratitude is expressed to Lake Region Travel, Keystone Heights, and Pattye McLean of that organization for assisting in planning meals, securing hotel reservations, and arranging transportation for the field trip. Designed Marketing Service and Jeanette Reynolds designed, printed, and distributed the registration forms. Very special thanks are due to Bobby Timmons for serving as a guest speaker at the conference banquet, and to Patti Crawford for typing the guidebook manuscript. The help from these organizations and individuals is greatly appreciated.

Many other individuals played important roles by conducting tours during the conference. E. A. Mallard served as tour guide for Du Pont's heavy mineral operations near Starke. Dick Beale directed a tour of Associated Minerals operations near Green Cove Springs, and Wayne Smith directed the visit at the Grandin Sand Plant. Sincere thanks are extended to these people for their help.

Also, thanks are extended to other individuals who gave valuable time and aid in organizing and helping to make the conference a success. Brian Stratford of Du Pont made important contributions to the field trip log. Danuta Malinowski drafted the field trip maps. Norm Stouffer, E. A. Mallard, Eric Arenberg, Ted Goodman, Rich Burklew, and R. C. Lindquist helped to prepare exposures at the Brooks Sink and Grandin sand sites for easier viewing by the field trip members. Again, sincere gratitude and appreciation is expressed to all of the companies and individuals who helped to make this field conference a success.
FIELD TRIP AND MEETING SCHEDULE

Friday, February 19, 1988

12:00 noon  Depart Best Western Motel for first stop at E. I. Du Pont heavy mineral mine on Trail Ridge in Clay County.

5:00 p.m.  Return to motel

6:00 p.m.  Cocktail hour at cash bar located in the reception and banquet room of the Best Western Motel.

7:00 p.m.  Dinner meeting with guest speaker Bobby Timmons in the banquet room of the Best Western Motel.

Saturday, February 20, 1988

8:00 a.m.  Depart headquarters for all day field trip in northeast Florida.

8:30 a.m.  Second stop at Associated Minerals (USA) Inc. in Clay County.

12:00 noon  Third stop and lunch at Brooks Sink in Bradford County.

3:00 p.m.  Fourth stop at abandoned sand mine in Putnam County.

4:30 p.m.  Fifth stop at Grandin sand plant in Putnam County.

6:00 p.m.  Return to motel.

Note: Scheduled timing is subject to minor changes.
Figure 1 - The area in northern Florida covered by the field trip is indicated by the rectangle. Heavy lines show the crests of several ridges.
Figure 2 - Route of field trip with stops numbered. The general location of the field trip area in northern Florida is given on Figure 1.
### SEGS - FEBRUARY, 1988

#### Field Trip Log

**Friday, February 19, 1988**

<table>
<thead>
<tr>
<th>Total Miles Traveled</th>
<th>Miles from Last Reference Point</th>
<th>Reference Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>Assemble, board bus and depart Best Western Motel, Orange Park, FL, at 12 Noon, travel south on US 17.</td>
</tr>
<tr>
<td>1.4</td>
<td>1.4</td>
<td>Turn right (west) onto Kingsley Avenue (SR 224).</td>
</tr>
<tr>
<td>4.1</td>
<td>2.7</td>
<td>Turn left (south) onto Blanding Boulevard (SR 21) pass through Middleburg, FL</td>
</tr>
<tr>
<td>16.0</td>
<td>11.9</td>
<td>Turn right (southwest) onto CR 215.</td>
</tr>
<tr>
<td>21.9</td>
<td>5.9</td>
<td>Turn right (west) at intersection of SR 16 - pass front gate at Camp Blanding 0.9 mile.</td>
</tr>
<tr>
<td>25.3</td>
<td>3.4</td>
<td>Turn left (south) SR 230</td>
</tr>
<tr>
<td>26.6</td>
<td>1.3</td>
<td>Turn left onto an unnamed road. There will be a green sign indicating Camp Blanding West Gate. Also, a Du Pont sign, Trail Ridge Site, with an arrow pointing left.</td>
</tr>
<tr>
<td>26.9</td>
<td>0.3</td>
<td>Turn left at dead end, then right after a hundred yards just before the Camp Blanding West Gate. Look for a small Du Pont sign with an arrow pointing right.</td>
</tr>
</tbody>
</table>
Du Pont is the largest domestic producer of titanium, zircon, and allied minerals from their two heavy mineral sand operations located in northeast Florida. The Trail Ridge plant began operations in 1948 on Camp Blanding property. The plant was expanded in 1955 when the Highland mine was opened. Both plants derive their feedstock from the Trail Ridge landform using continuous mining and processing methods. The plants currently employ approximately 260 people from the surrounding area. Additional land north of the Highland operation, along Trail Ridge, has been purchased by Du Pont. Evaluation, permitting and preparations for mining are now in progress with production estimated to begin in the early 1990s.

29.1 2.2 Stop #1 Arrive at office and dry mill complex of E. I. Du Pont.

58.2 29.1 Return to motel by 5:00 p.m.

Saturday, February 20, 1988

0.0 0.0 Assemble, board bus and depart Best Western Hotel, Orange Park, Florida, at 8:00 a.m. Travel south on US 17.

2.4 2.4 Cross over Doctors Inlet Bridge - St. Johns River on the left with Doctors Lake on the right.

9.4 7.0 Cross over Black Creek Bridge

11.9 2.5 Cross over Governors Creek Bridge at city limits of Green Cove Springs, Florida.

17.6 5.7 Virginia Village with Southland Lounge on left.

21.8 4.2 After passing over RR tracks turn right (west) onto Warner Road [sign - Associated Minerals (USA) Inc.]
The Green Cove Springs ore body was first mined by Titanium Enterprises, a joint venture of American Cyanamid and Union Camp Corporation, in 1972. In 1979 the operation was sold to Associated Minerals (USA) Inc., an Australian owned company.

The ore body strikes NW-SE and is located on Union Camp property about 1 to 3 miles west of Highway US 17 between Green Cove Springs and Palatka. The mineralized zone is approximately 12 miles in length and averages about 1 mile in width and 20 feet in thickness. Production of titanium minerals, zircon, and monazite has been continuous for 16 years except for a short period during the late 1970s at which time Titanium Enterprises sold the mining rights and all equipment to Associated Minerals. Since that time the reserves have been increased by leasing additional mineable property west of the original Green Cove Springs ore body.

<table>
<thead>
<tr>
<th>Total Miles Traveled</th>
<th>Miles from Last Reference Point</th>
<th>Reference Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.8</td>
<td>2.0 Stop #2</td>
<td>Arrive at Associated Minerals office and dry mill complex.</td>
</tr>
<tr>
<td>25.8</td>
<td>2.0</td>
<td>Return to US 17 and turn left (north).</td>
</tr>
<tr>
<td>30.3</td>
<td>4.5</td>
<td>Just past Southland Lounge in Virginia Village turn left onto CR 15-A.</td>
</tr>
<tr>
<td>33.7</td>
<td>3.4</td>
<td>Turn left (west) onto SR 16.</td>
</tr>
<tr>
<td>38.9</td>
<td>5.2</td>
<td>Penney Farms village located on the northern extension of land form containing the Green Cove Springs ore body.</td>
</tr>
<tr>
<td>45.2</td>
<td>6.3</td>
<td>Intersection of SR 21.</td>
</tr>
<tr>
<td>47.1</td>
<td>1.9</td>
<td>Fire tower and microwave tower on right.</td>
</tr>
<tr>
<td>51.7</td>
<td>4.6</td>
<td>Intersection of SR 225.</td>
</tr>
</tbody>
</table>
Saturday, February 20, 1988 (cont’d.)

<table>
<thead>
<tr>
<th>Total Miles Traveled</th>
<th>Miles from Last Reference Point</th>
<th>Reference Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>58.2</td>
<td>6.5</td>
<td>Intersection of US 301 in Starke, Florida – turn left (south) onto US 301.</td>
</tr>
<tr>
<td>61.9</td>
<td>3.7</td>
<td>After passing through Starke, Florida, turn right onto CR 227. Just past Christ Church on right, green sign giving directions to Brooker and Graham.</td>
</tr>
<tr>
<td>65.6</td>
<td>3.7</td>
<td>Intersection of CR 18 on left.</td>
</tr>
<tr>
<td>67.4</td>
<td>1.8</td>
<td>Village of Graham</td>
</tr>
<tr>
<td>69.5</td>
<td>2.1</td>
<td>Container Corporation forestry field office on right.</td>
</tr>
<tr>
<td>70.3</td>
<td>0.8</td>
<td>Turn right onto dirt road at second gate past CCA forestry office.</td>
</tr>
<tr>
<td>71.0</td>
<td>0.7 Step #3</td>
<td>Clearing and path on right. Brooks Sink about 50 yards on right (SW 1/4, SW 1/4, Sec. 12, T. 7 S., R. 20 E.).</td>
</tr>
</tbody>
</table>

The third stop is at Brooks Sink in southern Bradford County. This site and the Devil’s Mill Hopper near Gainesville are the cotype localities of the Hawthorne Formation. T. M. Scott (this volume) presents a section of the sediments exposed at this sink and discusses the Hawthorne sediments of north-central peninsular Florida. He uses the term Hawthorne as a group name, and gives characteristics of the individual group units that are exposed at the sink. Jones and Portell (this volume) discuss invertebrate fossils from the Hawthorne beds at the sink, and Morgan and Pratt (this volume) describe vertebrate remains collected from a bed that crops out near the bottom of the sink. Earlier sections measured at Brooks Sink include those presented by Sellards (1909), Pirkle (1956), and Espenshade and Spencer (1963).
<table>
<thead>
<tr>
<th>Total Miles Traveled</th>
<th>Miles from Last Reference Point</th>
<th>Reference Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>71.7</td>
<td>0.7</td>
<td>Return to CR 18 - turn left (east) onto CR 18 and CR 227.</td>
</tr>
<tr>
<td>76.4</td>
<td>4.7</td>
<td>Turn right (east) and continue on CR 18.</td>
</tr>
<tr>
<td>78.9</td>
<td>2.5</td>
<td>Intersection of US 301. Continue across US 301 through the small town of Hampton.</td>
</tr>
<tr>
<td>84.2</td>
<td>5.3</td>
<td>Turn right (southeast) onto SR 100.</td>
</tr>
<tr>
<td>88.9</td>
<td>4.7</td>
<td>Intersection in Keystone Heights, Florida.</td>
</tr>
<tr>
<td>92.8</td>
<td>3.9</td>
<td>Putnam County line.</td>
</tr>
<tr>
<td>95.6</td>
<td>2.8</td>
<td>Grandin sand plant on right.</td>
</tr>
<tr>
<td>96.0</td>
<td>0.4 Stop #4</td>
<td>Turn left (north) onto dirt road (church sign) for 0.1 mile. Abandoned sand mine on right.</td>
</tr>
</tbody>
</table>

During this stop sediments at the Grandin sand mine just west of Grandin in Putnam County will be examined. Sediments exposed at this site have been considered by various investigators as a part of the Citronelle Formation for many years. Other names applied to these sediments include such terms as the unnamed coarse clastics and the Fort Preston Formation (Puri and Vernon, 1964). Recently Barry Kane (1984) carried out detailed studies of these sediments at this sand mine and at other localities in Putnam County. He renamed the sediments referring to them as the Grandin sands. He cites the Grandin sand mine we are visiting at this stop as the type locality for the Grandin sands. He states (1984, p. 3):

It is suggested the terms Citronelle and Fort Preston Formation in referring to sands and gravels forming the Lake Wales Ridge be abandoned. It is proposed the term Grandin sand be used based on the type area at the Grandin sandmine in Grandin, Putnam County, Florida.
In the introduction to his section on fossils, Kane stated (1984, p. 42):

Paleontological studies on the Grandin sands are virtually nonexistent because of the lack of preserved fossils. This is perhaps the primary reason for such controversy over the depositional environment and age.

Pirkle et al. (1964) described pelecypod fossils discovered near the base of the Grandin sands in auger samples, but were unsure if they represented the lower Grandin or the upper portion of the Hawthorn formation...

Fossils found in the north central portion of the study area include bivalve mollusks, Ophiomorpha traces, and fecal pellets. The fossil horizon is approximately 30 m above mean sea level and best displayed along horizontal, weathered surfaces.

The abstract of Kane's study is presented at the end of this volume.

Tom Scott (this volume) takes an overall view of these clastic sediments in north-central peninsular Florida and renames them the Cypresshead Formation for exposures in a pit located on the south side of Goose Creek, 0.25 mile southeast of the confluence of Cypresshead Branch and Goose Creek, in Wayne County, Georgia.

96.4 0.4 Stop #5 Return to SR 100, turn right (west). Grandin sand plant of Florida Rock Industries, Inc.

This stop shows a fresh cut of the surface sands and underlying clayey sands. This particular sand plant was put into operation in September, 1987. The products produced from this plant are used in the building and construction industry throughout Northeast Florida.

103.6 7.2 Return to Keystone Heights intersection of SR 21. Turn right (north).

135.0 31.4 After passing through Middleburg turn right onto Kingsley Avenue past Orange Park High School (SR 224).
<table>
<thead>
<tr>
<th>Total Miles Traveled</th>
<th>Miles from Last Reference Point</th>
<th>Reference Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>137.6</td>
<td>2.6</td>
<td>Turn left (north) onto US 17.</td>
</tr>
<tr>
<td>139.0</td>
<td>1.4</td>
<td>Best Western Motel on left.</td>
</tr>
</tbody>
</table>

References


MINING FOR HEAVY MINERALS

Norman W. Stouffer
E. I. Du Pont de Nemours & Co., Inc.
Starke, Florida

Introduction

Heavy minerals have specific gravities of 2.9 or greater. The most common heavy minerals in the Florida surface sands include the titanium minerals - ilmenite, leucoxene, and rutile; the aluminum silicates - kyanite and sillimanite; the iron-bearing silicates - staurolite, epidote, and garnet; the rare earth phosphates - monazite and xenotime; and the zirconium silicate - zircon.

The specifics of any given heavy mineral sand mining operation are dependent upon the nature of that particular deposit and its mineral suite. However, the processing steps are all borne from the same technologies, and a generalization of heavy mineral mining can be drawn. The typical sequence of operation as used at the Trail Ridge site in Florida is illustrated in Figure 1 and described below.

Clearing

The purposes of this step are to remove vegetation which would interfere with the processing steps downstream, to remove top soil for future reclamation purposes, and to remove any non-ore surface sands (Fig. 1). It is typical to harvest woody plants 1 to 2 years ahead of the mining. This allows time for roots and other organic materials to partly decay before mining begins. The top soil needed for reclamation is removed to a depth of about 6 to 8 inches. Crawler-tractors and pan scrapers are usually used to remove any non-ore overburden not processed through the mills.

Mining

Where the water table is high enough to permit, mining is usually performed by a dredge (Fig. 1). The dredge floats in a pond of its own making. With either cutterhead or bucketwheel, the dredge bites into the front face of the pond, loosening the ore and pumping it as a slurry to the first processing mill. Dredging depths from as shallow as 10 feet to as deep as 70 feet are common in the industry. Dredges range in size from those capable of dredging 100 tons per hour to those that dredge over 3000 tons per hour. Simultaneously, the rejects, or tailings,
Figure 1 - Typical heavy mineral mining sequence
from the processing are pumped to the rear of the pond, backfilling behind the mining operation. The net effect is that a pond of nearly constant size moves slowly over the ore body as mining progresses. Since the heavy mineral content of most ore bodies is only a few percent, the land after mining approximates the contours and elevations of the land before mining.

In areas where lakes cannot be maintained, or in areas of surface ore too shallow for dredging, dry mining is accomplished by using shovels, front-end loaders, or pan scrapers. The raw ore is transported and dumped into hoppers where it is slurred with water and pumped to the first processing mill. The tailings from the process are either pumped or hauled back to fill mined areas.

**Wet Mill**

The first processing plant is the wet mill (Fig. 1). In this step, the heavy minerals are separated from the host quartz sand utilizing differences in specific gravity. This separation is performed with the ore slurried in water, hence the name wet mill.

The first step is to pass the ore slurry over screens to remove oversize material (generally greater than 1/4" in diameter). In areas of some ore bodies, clays or carbonized plant residues may be present in sufficient amounts to cement the sand grains together to form a poorly consolidated sandstone. Depending upon the amount of this cemented material, crushing to recover the sand with its included heavy minerals may be practical.

The gravity separation itself is usually performed with spirals. A spiral is a helical trough winding down a center column. The diameter of the spiral is usually two feet; height may be anywhere from four to twelve feet depending on the particular make and model of spiral. Slurry feed containing sand and water is introduced at the top of each spiral. As the material flows down and around the trough, lighter material such as silica sand is carried to the outside of the trough. The heavier minerals tend to concentrate near the inside of the trough and are drawn off at selected points.

The spirals themselves are normally arranged in stages, with all the spirals of a given stage performing an identical function. The number of spirals in a given stage is predetermined by the design rate of slurry flow to that stage. Normal loading on one spiral is one to two tons of sand per hour. Thus a stage processing 300 tons of sand per hour could be expected to have around 200 spirals.
Current wet mill practice usually calls for four stages of spirals. The number of stages may vary, however, depending upon the grade of the raw ore and the ease of mineral separation. The usual four stages are called roughers, cleaners, finishers, and scavengers. New, screened feed is first fed to the roughers. The concentrate from the rougher stage is further upgraded in the cleaner stage, and the cleaner concentrate is finally upgraded in the finishers to produce a wet mill concentrate grade of about 80-90% heavy mineral. Side streams from the cleaners and finishers are fed to the scavengers to recover and recycle heavy minerals back into the process. Tailings from the wet mill are generated from the roughers and from the scavengers. It is typical for a modest-sized wet mill, handling 1000 tons per hour of new feed, to have 1000-1200 spirals within these four stages.

With a few notable exceptions, wet mills are located close to the area of mining. This minimizes material handling, since wet mill feed and the return flow of wet mill tails are by far the two largest process streams in an operation of this type. In the case of a dredging operation, the wet mill usually floats in the pond near the dredge. The heavy mineral concentrate is pumped to a stockpile area ashore for transport to the next processing step. The tails are pumped to the back of the pond. Since the mining operation and hence the pond move, these lines to shore are relocated frequently to keep up with the mining operation.

In the case of a dry mining operation, the wet mills are generally kept relatively small so that they can be transported to the vicinity of the mining face as mining progresses. A practical limit is a plant that can handle about 500 tons per hour of new feed. The concentrates are again stockpiled nearby for transport to the next processing step.

Dry Mill

The dry mill is the first of the mills to separate the heavy mineral concentrate into its constituent minerals as products (Fig. 1). The physical properties most commonly used to make these separations are conductivity, magnetic susceptibility, and grain size. The selection and sequence of the separation steps in a dry mill are intimately tied to the particular mineral suite to be processed.

High tension separators and/or plate separators are the devices commonly used to segregate conductive minerals from non-conductive minerals. Both devices pass the feed through an electrical field to charge the sand grains. The high tension separation then pins the non-conductors, which retain their static charge, to a roller of opposite polarity. In a plate separator, the charged non-conductors are lifted from the process stream by passing under the influence of a large electrode of opposite polarity. The sand feed to each must be clean (free from surface coatings) and dry for these separations to be effective.
Magnetic separators come in many different types and styles. They can be adjusted over a range of magnetic intensities to differentiate one mineral from another.

Like spirals, the dry mill high tension separators, plate separators, and magnets are only partially effective in a single pass, and the equipment is generally staged to upgrade the concentrates or to scavenge from the tails. A typical dry mill flow sheet may be described as follows:

a. Wet mill concentrate is scrubbed to remove any residual clay or organic coatings. It is then dried and fed to the high tension separators. En route, screens remove coarse grains whose sheer mass will overcome the electrostatic effects of the downstream equipment, and therefore would not separate. If the coarse fraction contains valuable minerals, a separate circuit for processing would be required.

b. Several stages of high tension separators produce a conductor product and a non-conductor product. Plate separators are used as a final refining step on the conductors. The conductor stream consists of the titanium minerals ilmenite, leucoxene, and rutile.

c. Magnets are used to grade the titanium minerals, the lower grade minerals being more magnetic than the higher grade minerals. Once separated, the various grades of titanium concentrate are ready for shipment.

d. The non-conductor product from the high tension step is passed over magnets to pull the staurolite as a separate product from the mineral stream.

At this point, it is typical to feed the remaining non-conductor minerals to the zircon mill.

**Zircon Mill**

The purpose of this mill is to produce a quality zircon product from the tailings stream, and to produce a monazite product if that mineral is present in sufficient quantities (Fig. 1). The technologies are similar to the mills upstream - a wet mill step followed by a dry mill refining step. The task here is generally more difficult, since specific gravity differences are relatively small between the various residual heavy minerals in the tailings stream.
It is common to supplement the spiral stages in the wet portion of the zircon mill with what are called wet tables. These are also gravity separation devices, capable of a separation between small differences in specific gravity. The dry mill portion of the mill is used to remove any trace amounts of titanium or magnetic minerals.

Reject material from the zircon mill, normally rich in aluminum silicates, can be the basis for other products if an adequate product quality can be attained. Otherwise the rejects are stockpiled, returned to the mining area, or otherwise disposed of.

Environmental

Reclaiming the land and protecting the environment are essential parts of any heavy mineral mining operation. Since the heavy mineral grade in most ore bodies is only a few percent, very little material is removed from the land as mining progresses. Original contours are restored by careful placement of wet mill tailings with a touch-up by bulldozers. The topsoil, removed before mining, is placed back over the tails. The natural seeds and spores in the topsoil are supplemented with applications of grass seed and fertilizer. Once good ground cover is established, planting with native trees or bushes as desired by the landowner or required by the regulatory agencies is undertaken.

Water, including rain run-off, from the mining area and from the concentrate scrubbing facilities at the dry mill, is normally treated in settling ponds to eliminate suspended solids before discharge into the local environment.
THE HAWTHORN GROUP IN NORTHERN PENINSULAR FLORIDA

Thomas M. Scott
Florida Geological Survey
Tallahassee, Florida

Introduction

The Hawthorn Group in Florida is a complex deposit containing mixed and interbedded siliciclastics and carbonates. Phosphate occurs virtually ubiquiously throughout the group as discreet grains of carbonate fluorapatite (francolite).

The sediments of the Hawthorn Group have provided the focus of debate for many years since the naming of the unit by Dall and Harris (1892). For a review of the Hawthorn research and nomenclature, the reader is referred to Scott (1988).

Although the Hawthorn Group is recognized in the eastern panhandle and much of peninsular Florida, only the lithostratigraphy of the Hawthorn in northern Florida will be discussed in this guidebook. Discussion of the lithostratigraphy in other areas of the state can be found in Scott (1985; 1988) and Huddleston (1988).

Lithostratigraphy

The Hawthorn Group in northern Florida consists, in ascending order, of the Penney Farms Formation, the Marks Head Formation, the Coosawatchie Formation and the Statenville Formation (figure 1). These formational units are generally thickest in the Jacksonville Basin (figure 2) where the group is more than 500 feet thick (figure 3). The Hawthorn thins toward the Ocala Platform (figure 2) and is absent from its crest in west-central Florida (figure 4). It is also absent from the Sanford High (figure 2).

Penney Farms Formation

The Penney Farms Formation, named after the town of Penney Farms, Clay County, Florida, is a subsurface unit which is described from the type core Florida Geological Survey W-13769, Harris #1 in Clay County (Scott, 1988). This unit consists of carbonate, usually dolomite, interbedded with siliciclastics. This portion of the Hawthorn has been referred to as the basal carbonate section (Espenshade and Spencer, 1963). The siliciclastic portion of this unit increases upsection.

The carbonates of the Penney Farms Formation are variably quartz sandy, phosphatic, clayey dolostones. The dolostones are generally moderately to well indurated, very finely to coarsely
Figure 1 - Lithostratigraphic units of the Hawthorn Group in north Florida
Figure 2 - Structures affecting the Hawthorn Group
Figure 3 - Isopach of Hawthorn Group in Florida
Figure 4 - Top of the Hawthorn Group in Florida
crystalline. Colors range from medium gray (N 5) to pale yellowish brown (10 YR 6/2) and light olive gray (5 Y 6/1) in more clayey sections. Molds of mollusk shells are common. Intraclasts frequently occur in the dolostones of the basal portion of the Penney Farms. Limestone occurs only sporadically within this unit.

Quartz sands in the Penney Farms are fine to coarse grained, moderately to poorly sorted, subangular to subrounded, variably phosphatic, dolomitic and clayey. Induration is generally poor. Colors range from olive gray (5 Y 3/2) or grayish olive (10 Y 4/2) to medium light gray (N 6).

Clays are generally quartz sandy, phosphatic, and dolomitic. Accessory mineral concentrations are highly variable, however, beds of relatively pure clay are not common in the Penney Farms Formation. Colors vary from olive gray (5 Y 3/2) and grayish olive green (5 GY 3/2) to light olive gray (5 Y 6/1). The clays are usually composed of a mixture of smectite, illite, and/or palygorskite (Hettrick and Friddell, 1984).

The Penney Farms Formation unconformably overlies the Upper Eocene Ocala Group throughout much of northern Florida. It may lie unconformably on the Oligocene Suwannee Limestone in a limited area. The drastic difference between the underlying Paleogene limestones and the Penney Farms sediments provides a sharp, recognizable basal contact. It is overlain by the Marks Head Formation except in those areas where the Marks Head is erosionally removed. In these areas, the Penney Farms is overlain by post-Hawthon undifferentiated sands and clays. The top of the Penney Farms is placed at the break between the lighter colored sediments of the Marks Head and the darker colored Penney Farms sediments. Occasionally, the break is marked by a rubble zone of phosphatized dolomite clasts. The relationship of the Penney Farms to subjacent and suprajacent units is shown in figures 5 and 6.

The top of the Penney Farms Formation ranges from -333 feet MSL in Duval County to +150 feet MSL in Marion County (figure 7). This unit is absent from the Ocala Platform and the Sanford High. It thickens to the northeast reaching a maximum observed thickness in excess of 230 feet (figure 8). The dip of the unit is to the northeast at approximately 4 feet per mile.

The age of the Penney Farms, based on the limited data in Georgia and northern Florida, appears to be Aquitanian (early Early Miocene) (Huddlestun, 1988; Scott, 1988). Figure 9 shows the correlation of the Penney Farms Formation with other units in the southeast.
Figure 6 – Cross sections
Figure 7 - Top of Penney Farms formation (shaded area indicates undifferentiated Hawthorn Group)
Figure 8 - Isopach of Penney Farms Formation (shaded area indicates undifferentiated Hawthorn Group)
Marks Head Formation

Huddleston (1988) reintroduced the Marks Head Formation as part of the Hawthorn Group in Georgia. Scott (1988) extended this usage into Florida to encompass the middle unit of the Hawthorn Group in north Florida. The type section for the Marks Head occurs in outcrops at and near Porters Landing in northern Effingham County, Georgia. Reference sections in Florida are in Florida Geological Survey cores W-14219, Clay County and W-12360, Bradford County (Scott, 1988).

The Marks Head Formation in Florida consists of complexly interbedded quartz sands, clays, and carbonates. This unit is the most variable formation of the Hawthorn Group in Florida. The carbonates are characteristically dolostone with varying amounts of quartz sand, clay, and phosphate. Colors range from yellowish gray (5 Y 7/2) to olive gray (5 Y 4/1). Induration varies from poor to good. Crystallinity varies from microcrystalline to very finely crystalline. Mollusk molds and casts are often present.

The quartz sands are generally fine to medium grained, dolomitic, clayey, and phosphatic. Induration varies from poor to moderate. Colors are generally lighter than in the Penney Farms Formation and vary from light gray (N 7) to olive gray (5 Y 4/1).

Clay beds are quite common, occasionally comprising a large proportion of the section. The clays are quartz sandy, dolomitic and phosphatic. Colors of the clays vary from greenish gray (5 GY 6/1) to olive gray (5 Y 4/1). Clay minerals present include palygorskite, smectite, and illite (Hettrick and Friddell, 1984).

The Marks Head Formation unconformably overlies the Penney Farms Formation throughout much of northern Florida. It is unconformably overlain by the Coosawhatchee Formation except in those areas where the Coosawhatchee has been removed by erosion. When the Coosawhatchee is absent, post-Hawthorn undifferentiated sediments overlie the Marks Head. The contact between the Marks Head and the Coosawhatchee formations is generally placed at the top of the first hard dolostone or lighter colored clay bed below the darker colored, less complexly interbedded sands and carbonates of the Coosawhatchee Formation. A rubble bed may be present at the contact or there may be a phosphatized, bored hardground surface as is seen at Brooks Sink in Bradford County. Occasionally, the contact may appear gradational. When this occurs, the contact is placed at the top of the first hard carbonate bed below the darker colored Coosawhatchee sediments. The relationship of the Marks Head to subjacent and suprajacent units is shown on figures 5 and 6.
The Marks Head Formation occurs primarily as a subsurface unit. The top of the unit ranges from -260 feet MSL in Duval County to +110 feet MSL in Alachua County (figure 10). It is absent from the crest of the Ocala Platform and thickens to the northeast to 130 feet in northeastern Bradford County (figure 11). It is also absent from the Sanford High. The Marks Head generally dips northeast from the Ocala Platform toward the Jacksonville Basin at 4 feet per mile.

The Marks Head Formation has not yielded any datable fossils from the marine sediments in Florida. In Georgia, however, Huddleston (1988) has recognized planktonic foraminifera that suggest a late Early Miocene age (Burdigalian) for these sediments. Morgan and Pratt (this volume) identify microvertebrates from Brooks Sink that suggest a similar date. Correlations with the Marks Head are shown in figure 9.

Coosawhatchie Formation

The Coosawhatchie Formation was proposed as a formal unit of the Hawthorn Group in Georgia by Huddleston (1988). Scott (1988) recognized it as extending into Florida with only minor lithologic changes. The type locality is at Dawsons Landing on the Coosawhatchie River in Jasper County, South Carolina. The reference section for Florida is in Florida Geological Survey core W-13769, Harris #1, Clay County (Scott, 1988). One member is formally recognized in the Coosawhatchie, the Charlton.

The Coosawhatchie Formation in northern Florida consists of quartz sands, clays, and carbonates. The lower part is typically a dolomitic to nondolomitic, phosphatic, clayey quartz sand to quartz sandy clay. Dolomite increases in abundance in the upper portion and very dolomitic, phosphatic, clayey quartz sands to very quartz sandy, phosphatic, clayey dolostones predominate. Colors are darker in the lower section and lighter in the upper section, ranging from greenish gray (5 Y 6/1) and light gray (N 7) to olive gray (5 Y 4/1). Induration is generally poor in the sands and clays and poor to moderate in the dolostones. The clay mineralogy is dominated by smectite (Hettrick and Friddell, 1984).

The Coosawhatchie Formation unconformably overlies the Marks Head Formation throughout northern Florida. The Statenville Formation, which occurs in Hamilton and Columbia counties, in part overlies the Coosawhatchie conformably and in part interfingers with it laterally. Post-Hawthorn undifferentiated sediments unconformably overlie the Coosawhatchie. The relationship of the Coosawhatchie to subjacent and suprajacent units is shown on figures 5 and 6.
Figure 10 - Top of the Marks Head Formation (shaded area indicates undifferentiated Hawthorn Group)
Figure 11 - Isopach of Marks Head Formation (shaded area indicates undifferentiated Hawthorn Group)
The top of the Coosawatchie Formation ranges from -90 feet MSL in Putnam County to +168 feet MSL in Alachua County (figure 12). It is absent from the crest of the Ocala Platform and reaches a maximum thickness of 222 feet in Duval County (figure 13). The Coosawatchie dips northeasterly from the Ocala Platform toward the Jacksonville Basin at approximately 4 feet per mile.

The age of the Coosawatchie is better documented than the other units in the Hawthorn Group in northern Florida. Diatoms (Hoenstine, 1984) and foraminifera (Huddleston, 1988) indicate a Middle Miocene age (specifically early Serravallian). Correlations are shown in figure 9.

The Charlton Member of the Coosawatchie Formation


Characteristically, the Charlton Member consists of interbedded carbonates and clays. These sediments are less sandy than the Coosawatchie, often having very little to no sand. Phosphate is often absent in these sediments. The carbonates are generally dolostone, finely crystalline, and contain abundant mollusk molds. Limestone also occurs (as at Brooks Sink) and may be fossiliferous. Induration varies from poor to good. Colors range from light olive gray (5 Y 6/1) to yellowish gray (5 Y 8/1). The clays are dolomitic, silty, and may contain minor amounts of sand. Induration is poor to moderate and colors range from light gray (N 7) to greenish gray (5 GY 6/1). Clay minerals present include smectite, palygorskite, illite, and kaolinite (Hettrick and Friddell, 1984).

The Charlton Member of the Coosawatchie Formation appears to conformably overlie undifferentiated Coosawatchie and laterally interfingers with it. The Charlton appears to represent depositional environments during Coosawatchie time that received little influx of sand and phosphate. The Charlton is unconformably overlain by post-Hawthorn undifferentiated sediments. The relationship of the Charlton to subjacent and suprajacent units is shown on figure 5.
Figure 12 - Top of Coosawhatchie Formation (shaded area indicated undifferentiated Hawthorn Group)
Figure 13 - Isopach of Coosawhatchie Formation (shaded area indicates undifferentiated Hawthorn Group)
The Charlton Member occurs in a limited area of northeastern Florida and southeastern Georgia. Figures 14 and 15 show the recognized extent in Florida. The recognized distribution of the Charlton probably is the result of post depositional erosional processes. The top of the Charlton ranges in elevation from -38 feet MSL in Duval County to +145 feet MSL in Brooks Sink, Bradford County (figure 14). The maximum observed thickness is 40 feet in Nassau County (figure 15).

The age of the Charlton Member was originally thought to be Pliocene (Veatch and Stevenson, 1911). Huddleston (1988) based the age on molluskan faunas and stratigraphic relationships and postulated a Middle Miocene age. A marine ostracod fauna from the upper part of the Charlton Member at Brooks Sink was described by Puri and interpreted as late Middle Miocene and/or Late Miocene by Pirkle (1956, p. 210). Jones and Portell (this volume) recognize a Middle Miocene echinoid from the Charlton. Figure 9 shows the correlations with the Charlton.

Statenville Formation

The Statenville Formation consists of interbedded and often cross bedded phosphatic sands, clays, and dolostones. Named by Huddleston (1988) for exposures along the Alapaha River near Statenville, Georgia, the Statenville occurs in northern Florida in a limited area (figure 16). It is exposed along the Suwannee and Alapaha Rivers in Florida and is mined for phosphate in Hamilton County, Florida. The best section available is in the reference core Florida Geological Survey core W-15121, Betty #1, Hamilton County, Florida (Scott, 1988).

The Statenville Formation's lithology is similar to that of the Coosawhatchie Formation to the east. The diagnostic characteristic of the Statenville is that it is thinly bedded and often cross bedded while the Coosawhatchie is more coarsely or massively bedded. Quartz sands predominate in the unit. They are fine to coarse grained, clayey to dolomitic, poorly indurated, poorly to moderately sorted, subangular to angular, and range in color from very light gray (N 8) to light olive gray (5 Y 6/1). Phosphate grain content of the sands varies to greater than 40 percent making it economically feasible to mine. Dolostones are characteristically thin, quartz sandy, clayey, phosphatic, and poorly to well indurated. Colors range from yellowish gray (5 Y 8/1) to very light orange (10 YR 8/2). Clay beds present are sandy, sometimes dolomitic, phosphatic, poor to moderately indurated and range in color from light olive gray (5 Y 6/1) to yellowish gray (5 Y 8/1).
Figure 14 - Top of the Charlton Member (dashed line indicates extent of Charlton)
Figure 15 - Isopach of the Charlton Member (dashed line indicates extent of Charlton)
The Statenville Formation occurs in Florida in a limited area including Hamilton and Columbia counties (figure 16). It appears to conformably overlie Coosawhatchie Formation in some areas and to unconformably overlie Marks Head Formation in others. It is unconformably overlain by post-Hawthorn undifferentiated sediments. The maximum observed thickness is in the reference core Betty #1 where 87 feet of Statenville was measured.

The age of the Statenville is thought to be Middle Miocene (Huddleston, 1988). A zone of reworked Statenville sediments appears to be Late Miocene. This reworked zone was mapped by Brooks (1981) as Bone Valley Formation.

Post-Hawthorn Undifferentiated Sediments

The post-Hawthorn undifferentiated sediments in the north Florida area are composed of quartz sands, clays, and shelly sediments. The sands include the Cypresshead Formation (see discussion in this volume) and Pleistocene undifferentiated. The sandy clays and shelly sediments appear to fall in the Nashua Formation but have not been fully investigated.

Hawthorn Group in Brooks Sink

Brooks Sink provides the best natural exposure of Hawthorn Group sediments in Florida. Exposed in the walls of the sink and along the stream entering the sink are, in ascending order, the upper part of the Marks Head Formation, the Coosawhatchie Formation, and the Charlton Member of the Coosawhatchie Formation.

The Marks Head Formation occurs from the bottom of the sink to the top of the hard dolomite ledge from which the ladder descends. In outcrop, the Marks Head produces a very irregular exposure of the interbedded, well indurated and poorly indurated beds (figure 17). The hard ledges are composed of moderately to well indurated dolomite containing varying amounts of quartz sand and phosphate. The sediments of the softer zones are poorly indurated clayey dolomites, dolomitic clays and dolomitic, clayey sands. These sediments contain variable amounts of phosphate. Intraclasts of dolomitic clay and clayey dolomite are quite common in the softer beds. The microvertebrates described by Morgan and Pratt (this volume) were collected from this section.

Above the hard dolomite ledge marking the top of the Marks Head in the sink and along the stream draining into the sink, the Coosawhatchie Formation is exposed. The undifferentiated portion of the Coosawhatchie, below the Charlton Member, consists of interbedded siliciclastic sediments and carbonates. The sand and clay beds are more abundant in the Coosawhatchie than in the Marks Head (figure 17). All the sediments contain varying percentages of phosphate. Intraclasts are present in many beds but are not as common as in the Marks Head sediments.
Figure 17 - Diagrammatic section of Brooks Sink, Bradford County, Florida
The limestone exposed along the stream near the sink is placed in the Charlton Member of the Coosawhatchie Formation. These sandy, fossiliferous limestones have previously been placed in the Choctawhatchie Stage (see Jones and Portell, this volume). Based on litostratigraphic correlations with Charlton sediments identified by Huddleston (1988) as being Middle Miocene, it is suggested that this section belongs in the Middle Miocene. See Jones and Portell (this volume) for discussion of the suggested ages and the associated problems.

References


FOSSIL INVERTEBRATES FROM BROOKS SINK, BRADFORD COUNTY, FLORIDA

Douglas S. Jones and Roger W. Portell

Florida State Museum
University of Florida
Gainesville, Florida 32611

Introduction

Brooks Sink ranks among the most impressive, naturally-occurring geologic exposures in Florida. Located in Bradford County, just north of the Alachua-Bradford county line and approximately four miles east of the town of Brooker (SW 1/4, SW 1/4, Sec. 12, T. 7 S., R. 20 E.), the walls of this sinkhole reveal a section about 75 feet in height, depending on the current water level at the base of the sink (Fig. 1). The fine exposure combined with the importance of the units present have resulted in several geological studies at Brooks Sink with the earliest dating back to the beginning of this century.

Sellards (1909) was the first to describe the sequence of sediments in the exposure. His work stood for almost half a century until E. C. Pirkle (1956) redescribed the section in much more detail. Below a 15 foot covered interval at the top of the sink, Pirkle reported a thick shell marl which Dr. Harbans Puri (in Pirkle, 1956) was able to date on the basis of marine ostracodes as lower Choctawhatchee in age (late Middle Miocene and/or Upper Miocene). Exposed below this unit and extending to the base of the sink was a thick sequence of phosphate-rich beds of varying lithology which Pirkle (1956) considered to represent the Miocene Hawthorn Formation.

Pirkle’s section was later reprinted by Puri and Vernon (1964) when they designated Brooks Sink as a cotype locality (along with the Devil’s Mill Hopper near Gainesville) of the Hawthorn Formation. They placed the Hawthorn Formation in the Alum Bluff Stage and the overlying shell marl within the Choctawhatchee Stage. Subsequent remeasurements of the section have been reported by Espenshade and Spencer (1963) and Pirkle, Yoho, and Allen (1965). However, neither study advocated significant changes in age or lithologic interpretation.

More recently the Brooks Sink site has received attention from Thomas M. Scott and co-workers at the Florida Geological Survey as part of a continuing effort to refine and improve our understanding of the geologic framework of the Hawthorn Formation in Florida and its relation to overlying and underlying units (e.g., Scott, 1983; this volume). A new measured section at Brooks Sink was reported by Scott (1982) and is adopted here as a basis for location of fossil samples (Fig. 2). In the process of
Figure 1. Photograph of the north wall of Brooks Sink taken in December 1987. Dashed white line denotes contact between the Marks Head and Coosawatchie formations.
Figure 2. Lithologic section at Brooks Sink modified slightly from Scott (1982). Bed numbers represent those used in the text to locate fossil occurrences throughout the sequence. According to the latest stratigraphic revision of the Hawthorn Group at this site by T. Scott and co-workers at the Florida Geological Survey, beds 2 and 3 would correspond to the Charlton Member of the Coosawhatchie Formation, beds 4-15 belong to the Coosawhatchie Formation, and beds 16 down to the bottom of the exposure are assigned to the Marks Head Formation.
formally revising the Hawthorn, Scott (1986; in preparation; personal communication) proposes elevating the unit to group status. The Hawthorn Group would be composed of several formations which vary geographically between south Florida, north Florida, and the Florida Panhandle.

In their most recently measured section at Brooks Sink, Tom Scott and Richard Johnson of the Florida Geological Survey (personal communication, 10/20/87) consider the entire exposure (with the possible exception of four feet of undifferentiated sand and clay at the top) to fall within the Hawthorn Group. The lowest 20 feet of section correspond to the Marks Head Formation. Overlying the Marks Head is approximately 50 feet of the Coosawhatchie Formation. The upper 24 feet or so is termed the Charlton Member of the Coosawhatchie and includes the post-Hawthorn, Choctawhatchee Age shell bed of Pirkle (1956). Based on age assignments reported for these same units at the Devil's Mill Hopper State Geological Site, Scott (1986) considers the Marks Head Formation to be late Early Miocene in age and the Coosawhatchie Formation to be Middle Miocene.

Virtually every author reporting on Brooks Sink has noted the occurrence of fossils throughout the section. Yet, the fossil faunas of this important site remain very poorly known. This can probably be attributed to two factors: 1) the overall poor preservation of the fossils with most invertebrates represented only as casts and molds; and 2) lack of systematic prospecting for fossils by paleontologists. Our goal in this paper is to provide a preliminary assessment of the invertebrate fossil fauna at Brooks Sink and to consider its paleoecological as well as biostratigraphic implications. A companion paper by Morgan and Pratt (this volume) discusses the fossil vertebrates.

Invertebrate Fossil Fauna

Beginning with the simple section description of Sellards (1909, p. 240), the presence of shells and shell fragments at Brooks Sink has been noted by each succeeding investigator. The invertebrate fossils, however, have never been examined in more than a superficial manner. For example, the section descriptions of Pirkle (1956), Espenshade and Spencer (1963), Pirkle, Yoho, and Allen (1965), and Scott (1982) all indicate the occurrence of fossils at several horizons; but, the identifications are never more precise than " gastropod," " pelecypod," " barnacle," etc. Since the primary focus of these studies was not paleontology and because of the reasons cited earlier, little more is known of the fossil faunas (a notable exception being the ostracodes identified by Puri and reported in Pirkle, 1956).

In order to study the fossil invertebrates we relied upon collections housed at The Florida State Museum in Gainesville.
These collections primarily represent the field work of Dr. H. K. Brooks and students in the early 1970s and R. W. Portell in the mid 1980s. We also visited the site several times in 1987 to collect bulk samples of matrix for screen-washing as well as individual fossil specimens.

A preliminary faunal list which summarizes the taxa encountered and records their position in the section is included as Table 1. The bed numbers correspond to our own bed numbering system applied to the measured section of Scott (1982), presented in Figure 2. All of the fossil specimens are catalogued in the Invertebrate Paleontology Collection at The Florida State Museum with the exception of those followed by an asterisk in Table 1 (the bed 3 ostracodes and the barnacle from bed 17, reported by Pirkle, 1956). A subset of the fossils are photographed in Figure 3 to illustrate the diversity of taxa and the quality of preservation.

As Table 1 indicates, over 40 recognizable invertebrate taxa have been discovered. These range across seven phyla with the mollusks being the best represented. The poor preservation of calcium carbonate skeletons has limited the degree to which most taxa may be identified. This is reflected in the low percentage of forms which can be identified down to the species level. Most specimens are only identifiable to the generic or familial levels. No aragonitic skeletal material is present and most calcite has been leached or is at best recrystallized. Some has been replace by dolomite. The predominant mode of preservation is as casts and molds in a fine-grained mudstone or limestone matrix. This is exemplified by many of the specimens illustrated in Figure 3.

The occurrence of invertebrate fossils throughout the section is not uniform, as noted by Sellards (1909), Pirkle (1956), and subsequent authors. Certain horizons are highly fossiliferous whereas adjacent beds may be relatively devoid of fossils. A glance at Table 1 reveals that bed 3 is the most fossiliferous unit in the sink. This bed corresponds to the distinctly-bedded unit 19 shell marl of Pirkle (1956) and Puri and Vernon (1964) which they considered to be of Choctawhatchee age and to overlie the Hawthorn Formation. In the updated scheme of Scott and the Florida Geological Survey, this unit forms most of the Charlton Member of the Coosawhatchie Formation. Other, less abundant fossil occurrences are found lower in beds 11 and 13 of the Coosawhatchie and beds 17 and 19 of the Marks Head Formation. The vertebrate fauna discussed in the companion paper by Morgan and Pratt (this volume) is largely derived from bed 19 (with the exception of shark teeth which occur throughout).
<table>
<thead>
<tr>
<th>TAXON</th>
<th>BED NUMBER</th>
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<tr>
<td>Protista</td>
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<td>cheilostome, gen. and sp. undet.</td>
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<tr>
<td>Mollusca</td>
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<td>Gastropoda</td>
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<td>Bulla sp.</td>
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<td>Chione sp. cf. C. latilirata (Conrad)</td>
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<td>Mercenaria campechiensis (Gmelin)</td>
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<td>Modiolus sp.</td>
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<td>Ostracoda</td>
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**Haplocytheridea bassleri** Stephenson  
**Loxoconcha** sp. cf. **L. purisubrhomboidea** Edwards  
**Microcythere stephensoni** Puri  
**Murrayina gunteri** Howe and Chambers  
**Purana rugipunctata** Ulrich and Bassler  
**Xestoleberis choctawhatcheensis** Puri

Cirripedia  
**BALANIDAE, gen. and sp. undet.**  
3*, 13, 17*

Malacostraca  
**Callianassa** sp. cf. **C. floridana** Rathbun  
3, 11, 17

Echinodermata  
**Abertella aberri** (Conrad)  
3, 17

Trace Fossils  
3, 19

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* from Pirkle (1956). Bed numbers refer to Fig. 2.
Figure 3. Representative invertebrate fossils from Brooks Sink. UF numbers represent specimen catalogue numbers in the Invertebrate Paleontology Collection, The Florida State Museum, where the specimens are housed. 3.1) Arca sp. B, UF14412, length = 18 mm; 3.2) Pecten sp., UF14504, length = 14 mm; 3.3) Chione sp., cf. C. latillirata (Conrad), UR14485, length = 36 mm; 3.4) latex peel of Chione sp., UF14505, length = 14 mm; 3.5) Mercenaria campechiensis (Gmelin), UF14463, length of shell fragment = 49 mm; 3.6) Lithophaga sp., UF14430, commissural view (top) and side view (bottom), length = 29 mm; 3.7) Callianassa sp., cf. C. floridana Rathbun, UF14439, partial claw, length = 11 mm; 3.8) Conus sp., UF14427, height = 15 mm; 3.9) Praticolella sp., UF14411, width of specimen in matrix = 8 mm; 3.10) Praticolella sp., UF14405, width of specimen on latex peel = 10 mm; 3.11) coral impression, UF14462, overall length = 40 mm.
Paleoecology

The inability to refine the fossil identifications somewhat hinders the process of paleoecological reconstruction; nevertheless, several observations are noteworthy. Most of the invertebrates from Brooks Sink are indicative of shallow marine water conditions of fairly normal salinity. This is true of the majority of the gastropods and bivalves as well as the foraminifera, coral, bryozoans, arthropods, and echinoderms. Some of the bivalves such as Mercenaria, Modiolus, and certain other arks and pectinids are more characteristic of brackish water conditions, suggesting some mixing of faunal elements has occurred.

This hypothesis of mixing is further strengthened by the presence of freshwater and land snails in bed 3. Hydrobiids occur in great abundance within certain layers of bed 3, suggesting that intermittent freshwater discharges were common. Likewise, the occurrence of Praticolella (Fig. 3.9, 3.10), a land snail, similarly suggests co-mingling of the marine fauna with episodic input from the nearby non-marine environment. Although other polygyrid snails are known from the Miocene of Florida, this appears to be the first fossil record of the genus Praticolella (K. Auffenberrn, personal communication).

Certain beds (e.g. bed 3) within the sequence contain small crossbeds and some ripple laminations, indicative of abundant sediment movement. Burrowing bivalves such as Chione, Glycymeris, Lucina, and Nuculana along with Callianassa (burrowing shrimp) claws and burrows and sand dollars (Abertella) all support a relatively high energy, lower intertidal to subtidal paleoenvironmental interpretation. This contrasts with other beds such as 17 which warrant a slightly different interpretation. Bed 17 contains broken-up pieces of limestone which have been bored on all sides by the boring bivalve Lithophaga. Some limestone pieces also exhibit the cemented bases of barnacle attachments (Pirkle, 1956) while others reveal bryozoan encrustations. Such fragments with their trace fossil evidence suggest intervals of violent water agitation alternating with episodes of sediment by-passing or reduced sedimentation.

Biostratigraphy

The relatively poor preservation and resulting coarse fossil identifications definitely restrict the utility of the invertebrate fossils for biostratigraphy. Few of the taxa encountered are age diagnostic as most range throughout the Neogene. The ostracodes are a notable exception in this regard. In correspondence cited by Pirkle (1956), H. Puri wrote that the ostracodes from Brooks Sink (our bed 3) were well preserved, unlike the foraminifer which were leached and replaced by
dolomite. He was able to identify those species listed in Table 1 and felt the ostracode fauna was characteristic of a "lower Choctawhatchee age" which Pirkle (1956) interpreted as "late Middle Miocene and/or Upper Miocene." An informal reappraisal of Puri's ostracode identifications and correlations by Dr. Thomas Cronin of the U. S. Geological Survey (personal communication, 11/17/87) has reaffirmed the accuracy of Puri's identifications and correlations. These species of ostracodes occur primarily in the Voldia and Arca facies of the Choctawhatchee.

However, in terms of its age, the Choctawhatchee has been assigned a planktonic foraminiferal zone N17 age by Huddleston and Wright (1977) and is believed to pre-date the Messinian eustatic regression. Akers (1972) also reports an N17 (Late Miocene) age for the Arca zone of the Choctawhatchee Stage. Thus, the correlation would suggest an age of about 6-8 Ma for the bed 3 ostracode fauna; but, without direct planktonic foraminiferal data from this unit at Brooks Sink, it seems best to consider the age correlation tentative.

The only other invertebrate fossil in this section with biostratigraphic age connotations is the large sand dollar, Abertella aberti. A. aberti is known from the Hawthorn Formation at several sites around Florida as well as from the Choptank Formation of Maryland, the Pungo River Formation of North Carolina and the Chipola Formation of western Florida (McKinney, 1985). All of these occurrences suggest a Middle Miocene age for this clypeasteroid (McKinney, 1985). Such an age restriction is consistent with the presence of A. aberti in bed 17 at Brooks Sink but is difficult to reconcile with its appearance near the top of the section in bed 3. Either the stratigraphic range of A. aberti would need to be extended upward or the age estimates based upon the correlation of the ostracodes would need to be revised downward to accommodate this occurrence.

The vertebrate fossils from near the bottom of the Brooks Sink section (bed 19) suggest a late Early Miocene age of approximately 17-18 Ma (Morgan and Pratt, this volume). Hence it is possible that about 10 million years or so of Miocene time are spanned by the sediments at Brooks Sink.

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Geological Survey graciously furnished us with their latest measured section at Brooks Sink and Prof. E. C. Pirkle kindly accompanied us into the field and explained aspects of his earlier work at this site. This paper represents Florida State Museum Contribution to Paleobiology number 331.

Literature Cited


AN EARLY MIocene (LATE HEMINGFORDIAN) VERTEBRATE FAUNA FROM BROOKS SINK, BRADFORD COUNTY, FLORIDA

Gary S. Morgan¹ and Ann E. Pratt²

¹Florida State Museum
University of Florida
Gainesville, Florida 32611

²Department of Biology
Georgia Southern College
Statesboro, Georgia 30460

Introduction

Brooks Sink was first described in the geological literature nearly 80 years ago (Sellards, 1909) and has been discussed by many authors since that time (see Literature Cited). Yet only Espenshade and Spencer (1963) mentioned vertibrate fossils from this locality. They noted the presence of shark teeth in two separate layers in the lower half of the stratigraphic section. Brooks Sink was not known to contain land vertibrate fossils until very recently. While conducting field work in north Florida during the early 1980s, Donald B. Crissinger, a geologist for Mobil Chemical Company, discovered several teeth of the small three-toed horse, Archaeohippus blackbergi, in a phosphatic clayey sand layer near the bottom of Brooks Sink. Crissinger also collected several kilograms of sediment from this unit which he subsequently washed through a fine mesh screen and sorted under a binocular microscope. A large number of heteromyid rodent teeth were recovered from this small sediment sample, along with teeth of many other species of small mammals. Crissinger generously donated this important sample of fossils to the Florida State Museum in January 1984. G. S. Morgan accompanied Crissinger to Brooks Sink in October 1984 to collect additional material from the fossiliferous layer. They obtained another matrix sample that upon screen-washing yielded a large number of teeth and bones of small terrestrial mammals, along with abundant marine vertibrate, including sharks, rays, and teleost fish. Florida State Museum field crews have now visited the Brooks Sink site five times and have removed more than 300 kg (dry weight) of fossiliferous matrix. Most of this sediment has been washed and sorted and the vertibrate remains tentatively identified.

Brooks Sink is a large, nearly circular, vertical-walled sinkhole located in southern Bradford County in northern peninsular Florida. The exact location of Brooks Sink is 6 km east of Brooker and 1.2 km north of State Route 18 (SW 1/4, SW 1/4, Sec. 12, T. 7 S., R. 20 E., Brooker 7.5 minute quadrangle, 29°53'N, 82°16'W). The surface elevation at the top of the sink is 45 m. Brooks Sink contains one of the longest natural
geologic sections of the Hawthorn Formation (or Hawthorn Group of some authors) found anywhere in Florida. About 23 m of section are exposed depending upon the water level in the bottom of the sink.

Marine vertebrate fossils, particularly shark teeth, occur throughout the section exposed at Brooks Sink. However, the vertebrate fauna that constitutes the primary emphasis of this report, here designated the Brooks Sink Local Fauna (Florida State Museum Vertebrate Paleontology locality number BP01), occurs in a thin layer in a restricted region on the east wall of the sink near the bottom of the stratigraphic section. The Brooks Sink Local Fauna is derived from a 10 cm thick layer of grayish to bluish-gray (weathers to tan or buff) dolomitic clayey sand containing abundant light- and dark-colored grains and pebbles of phosphate, and rounded to angular clasts of clay or mudstone. The vertebrate fossils are derived from the coarse-grained phosphatic sediment deposited between the clay clasts. Measured stratigraphic sections of Brooks Sink have been published by several authors, including Pirkle (1956; reproduced by Puri and Vernon, 1964) and Scott (1982). The vertebrate fauna described here is derived from Unit 19 of Jones and Portell (this volume), which corresponds to Unit 1 of Pirkle (1956, p. 210) and the 21.5 m level in Scott’s section (1982, fig. 4, p. 242). The fossils occur in the lower third of Unit 19 between two thin, dense, ledge-forming dolomites. Figure 1 shows the stratigraphic position of the vertebrate-bearing unit at Brooks Sink.

The Brooks Sink vertebrate fauna is important for several reasons that will be discussed in more detail below: 1) land vertebrate fossils occur in the outcrop section of the marine Hawthorn Formation, thus allowing for correlation between marine and terrestrial biochronologies; 2) it is the only extensive sample of small mammals of latest early Miocene (late Hemingfordian) age in the eastern United States, and as such permits correlation with small mammal faunas of similar age from western North America; 3) the vertebrate fauna fills an important chronological gap in Florida Miocene small vertebrate faunas, recording the time period between the well known early Miocene (medial Hemingfordian) Thomas Farm Local Fauna in Gilchrist County and the recently discovered middle Miocene (early Barstovian) Nichols Mine fauna from Polk County in central Florida; 4) the site provides samples of certain taxa of small mammals previously unknown or very poorly represented in the early Miocene of eastern North America, including the small didelphid marsupial *Peratherium*, soricid and talpid insectivores, the mylagaulid rodent *Mesogaulus*, and sciurid and cricetid rodents.

**Age and Correlation**

The Brooks Sink vertebrate fauna is perhaps most important because it contains a rich sample of land mammals occurring in an otherwise predominantly marine geologic section, thus offering
Figure 1. Photograph of an abbreviated stratigraphic section at Brooks Sink showing location of vertebrate fauna (arrow). Stadia rod is 4.5 m in length. Unit numbers are those used by Jones and Portell (this volume) which were assigned to the 22 lithologic units in the Brooks Sink section of Scott (1982, fig. 4). Descriptions of the lithologic units are taken from Scott (1982). Units 16-19 in the abbreviated section shown here (4.5 m in length) include the same portion of the section corresponding to Units 1-6 of Pirkle (1956, p. 209-210) and the 16-21.5 m level of Scott (1982).
the rare opportunity for correlation between terrestrial and marine biochronologies. Tedford and Hunter (1984) recently compiled most of the available published information on Miocene land mammal faunas from Florida that were deposited in close association with marine geologic units. They correlated these Miocene faunas with the North American Land Mammal biochronology (Wood et al., 1941; Savage and Russell, 1983). North American Land Mammal Ages (NALMA) are biochrons characterized by a composite assemblage of land mammals, usually genera, that coexisted in North America during a particular interval of time. The characteristic mammalian assemblage for each NALMA has been constructed from correlative faunas throughout North America and contains genera that are either restricted to that age or have their first or last appearance during that age. The most reliable method for determining the relative age of fossil vertebrate faunas in Florida is through biostratigraphic comparisons with well-dated mammalian faunas from western North America using the land mammal biochronology. We have also made comparisons of the Brooks Sink Local Fauna with other vertebrate faunas of similar age in Florida.

Large land vertebrates (body weight greater than 5 kg) are uncommon in the Brooks Sink fauna which is dominated by small terrestrial mammals, particularly heteromyid rodents. This makes correlation of the fauna more difficult as the genera that define and characterize the Miocene NALMA are predominantly large mammals, especially carnivores, horses, and artiodactyls (e.g. Tedford and Hunter, 1984, fig. 1); however, there are certain genera of insectivores and rodents that are characteristic of the Miocene NALMA. The most diagnostic large terrestrial mammals from Brooks Sink are the diminutive, three-toed browsing horse Archaeohippus blackbergi and the larger, more hypsodont grazing horse Merychippus cf. M. gunteri. Both of these horses also occur in the latest early Miocene (late Hemingfordian) Midway Local Fauna, Gadsden County in the Florida panhandle (Fig. 2). Archaeohippus blackbergi is also known from two late early Miocene (medial Hemingfordian) faunas in Florida, the Thomas Farm Local Fauna, Gilchrist County and the Seaboard Local Fauna, Leon County (Fig. 2). The Thomas Farm and Seaboard faunas, along with the correlative Griscom Plantation Site, Leon County, all contain the horse Parahippus leonis, suggesting a slightly older age compared to Brooks Sink and Midway. Although the Midway fauna shares a number of taxa with Thomas Farm, it differs from the latter fauna in the presence of a somewhat more advanced horse, (Merychippus gunteri), a larger more hypsodont species of camelid, and a medium-sized dromomyrid, all of which are suggestive of late Hemingfordian assemblages from the Great Plains.

The occurrence of Merychippus gunteri at both Midway and Brooks Sink indicates a late Hemingfordian age for the latter fauna. The Midway fauna was discovered before the advent of screenwashing for microvertebrates. Moreover, the Fullers earth mine in which the site was located has long since been abandoned.
Figure 2. Map of Florida showing the location of the five best known Hemingfordian vertebrate faunas from the state: 1—Brooks Sink, Bradford County, late Hemingfordian; 2—Thomas Farm, Gilchrist County, medial Hemingfordian; 3—Seaboard, Leon County, medial Hemingfordian; 4—Griscom Plantation, Leon County, medial Hemingfordian; 5—Midway, Gadsden County, late Hemingfordian.
Fortunately, three taxa of small mammals are known from Midway. Midway is the type locality for the heteromyid rodents Proheteromys floridanus and P. magnus (Wood, 1932), both of which are now much better known from Thomas Farm (Wood, 1947; Black, 1963). Brooks Sink and Midway share the small heteromyid P. floridanus and the mylagaulid rodent Mesogaulus. The two larger species of Proheteromys from Brooks Sink are similar in size to P. magnus from Midway, but the Brooks Sink teeth are more hypsodont which may suggest a slightly younger age. Continued excavation at Brooks Sink should produce additional specimens of larger mammals permitting a refinement of this correlation.

The lower third (about 7 m) of the stratigraphic section exposed in Brooks Sink (Fig. 1), including the bed containing the Brooks Sink Local Fauna, has recently been referred to the Marks Head Formation based on lithologic comparisons (Scott, this volume). The Marks Head Formation was originally described from southern Georgia and has been correlated with the Torreya Formation of the Florida panhandle (Huddlestun, 1982; Hunter and Huddlestun, 1982). The Midway and Seaboard vertebrate faunas occur in the Torreya Formation (Hunter and Huddlestun, 1982; Tedford and Hunter, 1984). The Midway fauna occurs in the Carolina floridana macroinvertebrate biozone in the Dogtown Member in the upper portion of the Torreya Formation, whereas the Seaboard fauna is derived from the lower Torreya Formation (Hunter and Huddlestun, 1982). The superpositional relationship of these two faunas within the Torreya Formation reinforces the biochronologic data that suggest a slightly younger age for the Midway fauna. The type locality of the Marks Head Formation along the Savannah River in Effingham County, Georgia also contains Carolina floridana, along with Chlamys nematopleura, both of which suggest correlation of at least part of this unit with the upper Torreya Formation (Hunter and Huddlestun, 1982). A late Hemingfordian age for the Brooks Sink fauna is corroborated by the presence of planktonic foraminifera in the Marks Head Formation in southern Georgia that are characteristic of planktonic zone N6 and lower zone N7, indicating an age of 17-18 Ma (Huddlestun, 1982; Hunter and Huddlestun, 1982). These authors also correlated the Midway fauna with upper zone N6 and lower zone N7, further substantiating the similarity in age of Brooks Sink and Midway already established by comparison of their mammalian faunas.

Vertebrate Fauna

Excavation is still underway at Brooks Sink, and therefore the fauna from this locality will surely increase as more field work is conducted there. Because the site is being actively worked we have not attempted a detailed systematic review of the Brooks Sink vertebrate fauna. We have concentrated our discussion on several of the mammal groups that have been studied, particularly those of biochronological significance. The lower vertebrates from Brooks Sink have not been thoroughly analyzed. We have attempted to place generic identifications on
the sharks, rays, teleost fish, amphibians, and reptiles; however, in many instances only family-level identifications were possible. No diagnostic bird fossils have been identified from Brooks Sink.

As presently known, the Brooks Sink Local Fauna consists of 56 species of vertebrates: 11 species of sharks and rays; 6 species of teleost fish; 3 species of amphibians, all anurans; 13 species of reptiles, including a tortoise, 2 crocodilians, 7 lizards, and 3 snakes; and 23 species of mammals, including a marsupial, 3 insectivores, a bat, 9 rodents, 2 carnivores, 2 horses, 3 artiodactyls, a sea cow, and a cetacean (See Table 1 for a complete faunal list). The Brooks Sink fauna is composed of 20 taxa that inhabited marine or estuarine environments, 2 freshwater forms, and 34 terrestrial taxa.

The marine component of the Brooks Sink fauna consists primarily of isolated teeth of sharks, rays, and teleost fish. Also present are several rib fragments of sirenians, a tooth and a vertebra of the long-beaked dolphin Pomatodelphis, and two teeth of the extinct long-snouted crocodile Gavialosuchus. The majority of sharks, rays, and fish in the Brooks Sink fauna belong to living genera (Table 1). Comparisons with their modern counterparts provide useful information on the general habitat preferences of the various forms, and presumably on the depositional environment of the Brooks Sink vertebrate fauna (see Paleoecology discussion).

Three species of amphibians have been identified from Brooks Sink. The most common species is the tiny ranid frog, Rana abava. A toad (Bufo) and a tree frog (Hyla) are rare members of the fauna. Among the reptiles, tortoises (Geochelone) are represented by several shell fragments and small Alligator teeth are not uncommon. An impressive diversity of lizards is present at Brooks Sink, including seven species in six families, although most of the material, primarily consisting of partial dentaries and maxillae, is too fragmentary for generic identification. Osteoderms of the gila monster, Heloderma, are the only lizard fossils that are identified to genus. The composition of the lizard fauna from Brooks Sink is similar to the rich saurian fauna from Thomas Farm (Pratt, 1986). Snakes are not particularly abundant and most of the vertebrae are too broken to be identified, with the exception of the small burrowing snake Typhlops.

Carnivores and ungulates are poorly represented in the Brooks Sink fauna. Most of the taxa are known from one or at most several isolated teeth. Two carnivores are present in the fauna, an indeterminate mustelid and a tiny canid that has affinities with Phlaocyon. The two horses from Brooks Sink, Archaeohippus blackbergi and Merychippus cf. M. gunteri, have already been discussed in reference to their biochronological significance. Several partial teeth and a patella are recognizable as camelid, but are too incomplete for a generic identification. Two sizes
Table 1. Vertebrate faunal list from the early Miocene (late Hemingfordian) Brooks Sink Site, Bradford County, Florida.

Class Chondrichthyes
  Order Rajiformes
    Family Myliobatidae
      Aetobatus sp.
      Myliobatis sp.
    Family Dasyatidae
      Dasyatis sp.
    Family Pristidae
      Pristis sp.
  Order Lamniformes
    Family Carcharhinidae
      Carcharhinus leucas
      Carcharhinus sp.
      Galeocerdo aduncas
      Hemipristis serra
      Negaprion brevirostris
      Rhizoprionodon sp.
    Family Orectolobidae
      Ginglymostoma sp.

Class Osteichthyes
  Family Balistidae
    genus and species indet.¹
  Family Diodontidae
    genus and species indet.
  Family Sciaenidae
    Pogonias sp.
  Family Sparidae
    cf. Archosargus sp.
    Lagodon sp.
  Family Sphyraenidae
    Sphyraena sp.

Class Amphibia
  Order Anura
    Family Bufonidae
      Bufo sp.
    Family Hylidae
      Hyla sp.
    Family Ranidae
      Rana abava

Class Reptilia
  Order Chelonia
    Family Testudinidae
      Geochelone sp.
  Order Crocodilia
    Family Alligatoridae
      Alligator sp.
    Family Crocodylidae
      Gavialosuchus cf. G. americus
Order Squamata
  Suborder Sauria
    Family Iguanidae
      genus and species undet.² (two species present)
    Family Scincidae
      genus and species undet.
    Family Gekkonidae
      genus and species undet.
    Family Teiidae
      genus and species undet.
    Family Anguidae
      genus and species undet.
    Family Helodermatidae
      Heloderma sp.
  Suborder Serpentes
    Family Boidae
      genus and species undet.
    Family Colubridae
      genus and species undet.
    Family Typhlopidae
      Typhlops sp.

Class Mammalia
  Order Marsupialia
    Family Didelphidae
      Peratherium sp.
  Order Insectivora
    Family Soricidae
      new genus and species (?)
    Family Talpidae
      aff. Scalopoides sp.
      genus and species indet.
  Order Chiroptera
    Family Vespertilionidae
      genus and species indet.
  Order Rodentia
    Family Mylagaulidae
      Mesogaulus sp.
    Family Sciuridae
      undescribed genus (Pratt and Morgan, in press)
      cf. Tamias sp.
      petauristine (?)
    Family Heteromyidae
      Proheteromys floridanus
      Proheteromys spp. (two large species present)
    Superfamily Geomyoidea (Family Incertae Sedis)
      aff. Jimomys sp.
    Family Cricetidae
      genus and species undet.
  Order Carnivora
    Family Canidae
      aff. Phlaocyon sp.
    Family Mustelidae
      genus and species indet.
Order Perissodactyla
   Family Equidae
      Archaeohippus blackbergi
      Merychippus cf. M. gunteri
Order Artiodactyla
   Family Camelidae
      genus and species indet.
   Family Moschidae
      cf. Blastomeryx sp.
      cf. Machaeromeryx sp.
Order Sirenia
   Family Dugongidae
      genus and species indet.
Order Cetacea
   Family Schizodelphidae
      cf. Pomatodelphis sp.

1 genus and species indet. (indeterminate) indicates that the material of a particular taxon is insufficient for a more complete identification.

2 genus and species undet. (undetermined) indicates that the material of a particular taxon, although in some cases abundant and well preserved, has not been studied in sufficient detail for a more complete identification.
of small ruminant artiodactyls are represented at Brooks Sink by isolated teeth. These specimens are similar to teeth of the two small ruminants from Thomas Farm that have been referred to the genera Blastomeryx and Machaeromeryx.

Most of the identifications of the small mammals from the Brooks Sink fauna are tentative owing either to limited sample sizes or lack of adequate comparative materials of similar taxa from western North America. Thorough systematic studies are planned for the better represented small mammal taxa, in particular the marsupials, soricid insectivores, and the sciurid, heteromyid and cricetid rodents. About ten cheekteeth from this site are referable to the small didelphid marsupial Peratherium. The Brooks Sink Peratherium is one of the last North American records of this early marsupial lineage. The youngest previous record of Peratherium is from the early Hemingfordian Black Bear Quarry II Local Fauna, South Dakota (Green and Martin, 1976). Although as yet unpublished, a small sample of upper and lower teeth of Peratherium is also known from the early Barstovian Nichols Mine fauna in central Florida. The small marsupial Nanodelphys has been reported from the early Barstovian of Texas (Slaughter, 1978). R. G. Wolff (in prep.) is currently reviewing the taxonomic status of Oligocene and Miocene didelphid marsupials from Florida.

A very small species of shrew (Soricidae) is represented in the Brooks Sink fauna by about 15 teeth, including several mandible and maxillary fragments. The only other soricid known from the early Miocene of Florida is an undescribed species of Limnoecus from Thomas Farm. The Brooks Sink shrew differs from the Thomas Farm Limnoecus in its smaller size and certain morphological features of the lower molars. The soricid from Brooks Sink compares closely in size with the tiny shrew Antesorex compressus from the early Hemingfordian Martin Canyon fauna, Colorado (Wilson, 1960; Repenning, 1967); however, it seems to differ from the latter species in several important dental characters, and may represent an undescribed genus.

There are two genera of moles (Talpidae) in the Brooks Sink fauna. A large species is known from two isolated teeth and a toe bone. The teeth are similar in size and morphological features to Scalopoides, a genus known from the Hemingfordian of Colorado (Wilson, 1960) and South Dakota (Martin, 1976) and the Barstovian of Oregon (Hutchison, 1968). The second species of mole from Brooks Sink is much smaller than Scalopoides and considerably different in dental morphology. This small mole is represented by a single broken upper molar, although a well-preserved upper molar of a similar taxon has been found in the Barstovian Nichols Mine fauna. This mole is similar in size and dental features to the Hemingfordian through Clarendonian genus Mystipiterus and several other poorly known small talpids from the Barstovian of Oregon (Hutchison, 1968). The three talpid teeth from Brooks Sink constitute the oldest record of moles from eastern North America. Bats are represented at Brooks
Sink by a single upper molar of a small vespertilionid.

Two complete and several partial teeth from the Brooks Sink fauna are referable to the mylagaulid rodent Mesogaulus. Mesogaulus is the characteristic mylagaulid of Hemingfordian land mammal faunas in western North America (e.g. Black and Wood, 1956; Wilson, 1960). A. E. Wood (1947) reported a single lower premolar of Mesogaulus from the Midway fauna. This specimen is similar to the only comparable tooth from Brooks Sink. Sciurid rodents are represented at Brooks Sink by three species: a small form referable to a new genus of chipmunk (Pratt and Morgan, in press), a species similar to taxa from western North America usually referred to the Recent genus Tamias, and a form that may have affinities with the petauristine flying squirrels.

The most abundant small terrestrial mammals in the Brooks Sink fauna are two large species of the heteromyid rodent Proheteromys, represented by several hundred isolated cheekteeth. Both of these species have more hypsodont teeth than P. magnus, the large heteromyid from Midway (Wood, 1932) and Thomas Farm (Wood, 1947; Black, 1963). A rarer small heteromyid from Brooks Sink is referable to P. floridanus, a well known species previously reported from three other Florida Hemingfordian localities, Midway (Wood, 1932), Thomas Farm (Wood, 1947; Black, 1963), and Seaboard (Olsen, 1964). Two teeth of a large geomyid rodent are known from Brooks Sink. These teeth most closely resemble those of jimomys, a geomyid of uncertain affinities from the early Barstovian of Nebraska and Texas (Wahlert, 1976).

A small sample of cricetid rodent teeth from Brooks Sink appears to be more similar to primitive North American forms such as Leidymys than to the more advanced Copemys. Copemys is an Old World immigrant whose first appearance defines the beginning of the Barstovian land mammal age in North America (Tedford and Hunter, 1984). Cricetids are very rare in Hemingfordian faunas in North America (Martin, 1980). Black (1963) reported two cricetid teeth from Thomas Farm, but these specimens bear little resemblance to the Brooks Sink cricetids.

A brief comparison of the small mammal faunas from Brooks Sink and Thomas Farm is informative, as these two sites have produced the only diverse Hemingfordian microvertebrate faunas in eastern North America. Although only one to two million years separate these two faunas, they have only three genera in common. Both Brooks Sink and Thomas Farm have the small heteromyid rodent Proheteromys floridanus, a species of an undescribed genus of tiny sciurid (Pratt and Morgan, in press), and similar species of the small didelphid marsupial Peratherium. The Brooks Sink mammalian fauna includes two talpids, possibly an undescribed genus of soricid, Mesogaulus, two sciurids, a geomyid, and a cricetid, all of which are absent from Thomas Farm. Thomas Farm has a diverse fauna of bats, the soricid Limnoecus, an eomyid, and the large petauristine sciurid Petauristodon, all of which are lacking from Brooks Sink. The differences between these two
microvertebrate faunas may be attributable to paleoecological biases. The small mammals from Brooks Sink do, however, appear to be somewhat advanced over those from the slightly older Thomas Farm site.

Taphonomy and Paleoecology

Several features of the Brooks Sink vertebrate assemblage indicate a complex depositional history for the site. The fauna is dominated by marine vertebrates, in particular sharks and rays, and by terrestrial microvertebrates, primarily heteromyid rodents. Remains of larger terrestrial vertebrates are rare and mostly fragmentary.

Isolated incisors and cheekteeth of large heteromyid rodents are the most common terrestrial vertebrate fossils in the Brooks Sink fauna. Many of these teeth show evidence of breakage and water wear. The majority of the incisors are broken and the cheekteeth lack roots. Postcranial elements of small mammals consist primarily of small dense bones that are most resistant to breakage and abrasion, such as carpals, tarsals, and phalanges (Korth, 1979). Limb bones are rare and are represented only by resistant articular ends. As with the cheekteeth, there is evidence of water wear, but the effects of abrasion are not extreme. The marine component of the fauna exhibits a higher degree of water wear than do the terrestrial remains.

The sheer abundance of rodents (over four cheekteeth per kilogram of dry sediment) suggests that the original source for the terrestrial component of the fauna may have been an accumulation of microvertebrate remains. Assemblages of this type, termed coprocoenoses, are formed by mammalian or avian predators that feed on small mammals and other vertebrates and then eliminate the non-digestible portions (bones and teeth) in feces or pellets (Mellott, 1974). The predominance of one species of heteromyid, the rarity of large vertebrate remains, the high degree of bone breakage, and the rarity of complete limb bones, all provide evidence that the original bone source may have been a coprocoenosis (Korth, 1979; Andrews and Nesbit Evans, 1983; Maas, 1985).

Transport of the terrestrial component of the Brooks Sink vertebrate fauna in running water is indicated by the condition of the bones and teeth. The fossils were probably not transported a great distance based on the minimal degree of water wear on the bones. The size range of the fossils is suggestive of a fairly slow current velocity at the site of deposition. The predominance of bones having quartz grain equivalent diameters ranging from 0.25 to 1.1 mm indicates that these elements were transported by a current with a velocity of about 30-35 cm/sec. (Allen, 1965; Behrensmeyer, 1975). The rarity of larger bones may be evidence that current velocities were not sufficient to cause their transport and deposition.
Although it appears that the terrestrial microvertebrate component of the deposit may have been derived in part from a coprocoenosis that was winnowed by moving water, the mechanisms by which deposition occurred remain unresolved. The most probable sequence of events would involve the transport of the terrestrial vertebrate assemblage by a river or stream into a shallow marine depositional environment where admixing with the marine component of the fauna occurred. However, the absence of freshwater fish, salamanders, and turtles is difficult to explain if the fossils were transported by a freshwater stream.

A complete picture of the paleoecological setting of the Brooks Sink fauna has not yet emerged because the study of the site is still in its preliminary stages. The mixture of terrestrial, freshwater, and marine vertebrates in the fauna points to a complex depositional history for the site. Among the sharks present in the Brooks Sink fauna, Carcharhinus leucas, Negaprion brevirostris, Galeocerdo, Rhizoprionodon, and Ginglymostoma are all typical of shallow, inshore waters in subtropical or tropical seas. The first three of these sharks commonly enter bays, lagoons, and estuaries, while species of Rhizoprionodon and Ginglymostoma are confined to shallow, nearshore marine habitats. Most myliobatid and dasyatid rays are shallow-water bottom-dwellers. The teleost fish fauna is composed primarily of species commonly found in subtropical inshore marine environments, particularly barracuda (Sphyraena), trigger fish (Balistidae), and porcupine fish (Diodontidae). The extinct crocodilian Gavialosuchus also appears to have favored estuarine and nearshore marine habitats (Morgan, 1986).

The terrestrial component of the Brooks Sink vertebrate fauna is dominated by two larger species of the heteromyid rodent Proheteromys. This is not unusual as heteromyids are the most common rodents in nearly all Florida early Miocene faunas (Pratt, 1986). The Brooks Sink heteromyids were probably similar in overall morphology to the Recent Neotropical quadrupedal genera Heteromys and Liomys. The small heteromyid P. floridanus is comparatively rare at Brooks Sink, whereas this species overwhelmingly dominates the small mammal fauna from Thomas Farm. The three species of sciurids from Brooks Sink are all suggestive of wooded habitats. The more arid-adapted spermophiline sciurids are absent in this fauna. The abundance of lizards is another feature usually indicative of forested habitats in Florida. Birds are absent from Brooks Sink and bats are represented by a single tooth, indicating that the coprocoenosis did not form in a cave. These two groups are generally uncommon to rare in fluvial or deltaic depositional environments. Birds and bats are both common at Thomas Farm, which probably formed in association with a cave (Pratt, 1986). The most numerous anuran in Brooks Sink is a tiny ranid frog that was probably aquatic, although its small size suggests that it did not require a large or permanent water source. The overall paleoecological setting for the terrestrial component of the Brooks Sink vertebrate fauna could perhaps best
be described as a coastal savanna. Many members of the fauna probably inhabited forests alongside a stream, although grassland-adapted forms are present as well, including the horse *Merychippus gunteri*.

Several major questions concerning the Brooks Sink fauna remain unresolved: 1) Why are fossils of larger vertebrates, particularly ungulates, so rare in the deposit? 2) If the fossils were deposited by a fluvial system, why are freshwater vertebrates so uncommon?; 3) Are the terrestrial and marine components of the fauna the same age or do they represent two separate vertebrate assemblages that have been reworked into the same deposit? Although some transport and mixing of faunas was obviously involved in the formation of the site, there is little evidence to suggest significant reworking or that the fossils represent widely different ages. Despite the bias in favor of microvertebrates, the terrestrial vertebrate fauna from Brooks Sink appears to represent a uniform assemblage of late early Miocene (late Hemingfordian) age.

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We express our deep gratitude to Donald B. Crissinger who discovered the Brooks Sink vertebrate fauna, brought the site to our attention, and generously donated an important sample of fossils from the site to the Florida State Museum. Without his astute field work and amazingly keen eye this paper could never have been written. Glenn Harris and Joe Gissy of the Container Corporation of America graciously permitted us access to Brooks Sink. Arthur R. Poyer helped collect, wash, and sort most of the fossiliferous sediments so far obtained from Brooks Sink. Roger W. Portell assisted with field work and many other aspects of this study. Douglas S. Jones took the photograph in Figure 1 and David Kendrick printed the photograph. Richard C. Hulbert, Jr. provided the identifications of the fossil horses. This is University of Florida Contribution to Paleobiology Number 332.

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THE CYPRCHASE FORMATION IN NORTHERN PENINSULAR FLORIDA

Thomas M. Scott
Florida Geological Survey
Tallahassee, Florida

Introduction

The Cypresshead Formation is a new formational name in the stratigraphic nomenclature of Florida. It is being applied by the Florida Geological Survey to those sediments in the peninsular area that had been referred to in the past as the Citronelle or "Citronelle" Formation, Citronelle-like sediments and the Ft. Preston Formation. Huddlestun (1988) applied the name Cypresshead to sediments in southeastern Georgia that had previously been assigned to a number of units including lithologic and terrace formations. Although the Cypresshead Formation is thought to be the same age as the Citronelle Formation in western Florida, southwestern Georgia, and Alabama and the Miccosuckee Formation in the eastern Florida panhandle and central-southern Georgia, the application of the new nomenclature to these sediments is desirable since the units are not traceable into each other. These sediments are lithologically similar to the Citronelle in western Florida. However, the Cypresshead sediments in the peninsular area are separated from the Citronelle by the Miccosuckee Formation and by a large area where these sediments have been removed by erosion. As such, the use of the name Cypresshead Formation is recommended by the Florida Geological Survey to help alleviate the existing confusion and to aid in interstate correlations.

Type Locality

The term Cypresshead is taken from Cypresshead Branch in Wayne County, Georgia. The type locality is a sand pit on the south side of Goose Creek, 0.25 mile southeast of the confluence of Cypresshead Branch and Goose Creek. The pit is located on an unnamed county road 0.7 mile north of the intersection of the county road and Georgia Highway 169.

Lithology

The Cypresshead Formation is composed almost entirely of siliciclastics. Although not yet recognized in Florida, shells are reported to occur very sporadically in the Cypresshead of southeastern Georgia (Huddlestun, 1988). In the areas where the Cypresshead crops out, the sediments are characteristically oxidized and mottled. Shades of red, orange and white predominate.
The sands are predominantly quartz with minor amounts of feldspar and heavy minerals. The sands range in size from fine to very coarse, often including quartz pebbles. These sediments vary from poorly to well sorted and subangular to rounded. Induration is generally poor to nonindurated. The binding or cementing agent is normally clay although iron oxide cement is known to occur.

Clays are present throughout the Cypresshead Formation as a binding agent and occasionally as a primary lithology. Clay content of the sands ranges from less than one percent to 50 percent with an average of 10–20 percent. Clay content of the sediments appears to decrease in a general north to south trend with a greater average clay content in southern Georgia than in northern Florida. The clay mineral present in the oxidized, mottled portion is characteristically kaolinite while in the downdip, unoxidized portion illite and smectite dominate.

There are a number of excellent descriptions of these sediments available in the literature. Pirkle et al. (1963) provide some of the best descriptions and the reader is referred to this reference for detailed descriptions.

Stratigraphic Relationships and Area of Occurrence

Hawthorn Group sediments underlie the Cypresshead Formation unconformably throughout much of northern Florida. Where the Charlton Member of the Coosawatchie Formation of the Hawthorn Group occurs, the Cypresshead lies unconformably on it. Outside the area of Charlton occurrence, the Cypresshead lies on the undifferentiated Coosawatchie in northern Florida and the undifferentiated Hawthorn Group in central Florida (Scott, 1988).

Younger dunes and sand soils overlie or are developed on the Cypresshead in its outcrop area. The stratigraphic relationship of the Cypresshead to overlying, younger Pleistocene units to the east (Satilla and Anastasia for example) is thought to be unconformable (Huddleston, 1988). The eastern extent of the Cypresshead in the subsurface has not been determined at this time.

Huddleston (1988), in defining the Cypresshead Formation, stated that the unit correlated laterally with the shelly sediments of the Nashua Formation. Based on examination of a number of cores in central and western Nassau County by the author, this relationship appears to hold true in northern Florida also.

The Cypresshead Formation is widespread in northern peninsular Florida. It thins toward the west onto the flanks of the Ocala Platform where it is absent. The Cypresshead is thickest in the Central Highlands where it crops out and may attain thicknesses in excess of 200 feet in Lake County.
The Florida Geological Survey is currently conducting research into determining the nature of the Cypresshead Formation in Florida. This investigation will determine the lateral extent, lithologic variability, and thicknesses of the unit in peninsular Florida.

References

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ORIGIN OF THE GRANDIN (PLIO–PLEISTOCENE) SANDS, WESTERN
PUTNAM COUNTY, FLORIDA

Barry C. Kane

Department of Geology
University of Florida
Gainesville, Florida 32611
M. S. Thesis

Abstract

Sands and gravels form the northern extension of Lake Wales Ridge in western Putnam County. Physical and biogenic structures reveal dynamic marine sedimentary processes were responsible for accumulation of deposits referred to as the Grandin sands.

Several types of cross-stratification are recognized from bedding and foreset geometries. Structures imply a range of current velocities were responsible for bedform development. Statistical analyses of paleocurrent data show net sediment transport was generally to the south with lesser coeval currents oriented east-west. Sand body geometry expressed in surface exposures is an elongate ribbon or prism roughly paralleling the axis of the peninsula.

Fossil marine bivalve mollusks and Ophiomorpha spp. traces have been found at several localities within the study area. Pelecypod shell morphologies resemble the surf calm Mercenaria spp., and the razor clam Ensis spp. Ophiomorpha spp. trace fossils are believed to be fossil equivalents of structures produced by the modern marine decapod Callianassa spp. These organisms are closely associated with nearshore marine environments.

Distinct lithologic and biogenic associations within the Grandin sands allow discrimination of the following facies: bivalve and burrowed, burrowed trough cross-beded, burrowed planar cross-beded, and unstructured. Vertical sequence of these facies is interpreted to represent a prograding shoreline.

Clastic sediments were transported from the southern Appalachian mountains to the study area where tidal and longshore directed currents controlled sand body geometry. A post-Grandin transgression reworked the uppermost portion of the deposits. Pleistocene marine sands overlie the disconformity.

1Present address Western Geophysical Co., Houston, Texas