

**Southeastern Geological Society  
Field Trip Guidebook No. 50**



**Central Florida's Sand Mining District**



The Swamp Fox (Photo by M.Hurst)

**October 16, 2010**

**edited by Marc V. Hurst, P.G.**

**co-sponsored by the**

**Florida Association of Professional Geologists  
A Section of the American Institute of Professional Geologists**





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Southeastern Geological Society  
FAPG – A Section of AIPG



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## **INTRODUCTION**

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Florida is internationally famous for its white sand beaches. Unfortunately, very few of the state's sand deposits are suitable for commercial applications. They are generally too well sorted and too fine grained.

Our state is equally famous for its phenomenal rate of development. In the last century Florida's resident population has exploded by a factor of 25, to more than 18 million. In addition, more than 80 million persons visit Florida every year. The vast infrastructure requirements for accommodations for our visitors and residents has fueled a lively aggregate industry. After all, buildings, roads, and bridges are just cleverly-shaped piles of aggregate, held together by minimal proportions of cement and steel. When a new building rises from the ground, an excavation must be made somewhere else to supply the raw materials.

“The Ridge” area that we will visit on this field trip was virtually uninhabited until the mid 1800's. The first land surveys were made as railroads were built and the regions forest resources were exploited, primarily for naval stores. Railroads made the region more readily accessible. Extensive citrus and cattle industries developed. By the early 1900's a tourist industry had begun to develop. The early hotels and resorts that were built along the path of the South Florida Railroad through Davenport, Haines City, and Lake Wales were precursors of the region's modern tourist industry.

Small sand mines had begun to operate in the area by the 1940's. However, large-scale sand mining did not begin until the early 1960's, when Interstate-4 was built. The demand for large volumes of high quality sand for construction of concrete pavement kick-started large-scale sand production in the region. The completed highway was the basis of a new transportation and development corridor that brought a sustained demand for high quality sand products. New markets for sand were opened when construction of Walt Disney World, and related projects, began in the late 1960's. Suddenly, a region that had been almost vacant, except for orange groves and cattle ranches, became a very desirable place to visit, or to inhabit. The rate of tourist and residential development in Central Florida exploded.

Large-scale residential development in the field trip area did not begin until the early 1990's. Since then, the once-rural Ridge Area's population has mushroomed. And so has the sand industry.

Deposits of suitably pure silica sand, with a variety of grain sizes, including the coarse size fractions that are so rare in most of the state, are found almost exclusively along a relatively narrow North-South oriented zone that follows the center of the Florida Peninsula. The trend consists of a series of linear ridges, composed of relatively-ancient coastal marine sediments.

They are not drastically different from the tourist-coveted beaches of the current coast line, except that they have been uplifted to elevations almost of 300 feet above sea level and subjected to intense subaerial weathering.

The sand found in the Central Florida Sand Mining District had a long and complicated history. Interestingly, like our tourist visitors, the sand is not native to Florida. It traveled here from the distant metamorphic terrains of neighboring states.

The high quality of the sand is owed at least partially to its long journey south into Florida. Along the way it was subjected to a degree of physical and chemical attrition that designers of modern beneficiation plants can only dream of. As the sands were transported to Central Florida, numerous cycles of reworking in the marine environment classified and concentrated the sand grains. Only the physically strongest grains survived.

Subaerial weathering further purified the sand deposits after they were deposited. Many of the chemical impurities of the marine environment that are undesirable for commercial sand applications, including carbonates, alkalis, and organic constituents, are more soluble than quartz. Over a period of time, they were leached away. Only the most chemically-stable grains survived. The resulting deposits are chemical residuums, composed almost exclusively of silica.

A variety of methods have been used to mine sand in Central Florida. Schematic cross sections of four methods are shown in Figure 1. In the simplest case, shown in Figure 1A, mining is restricted to depths shallower than the water table. In some of the highest ridge areas, where water tables are very deep, there is no need to handle water; percolation rates of the sand deposits typically exceed rates of rainfall.

Most Central Florida sand mines are relatively deep. Thicknesses of typical deposits range from 50 to 70 feet. And most of the area's sand mines are located in areas where water tables are relatively shallow. Dewatering, illustrated schematically in Figure 1B, is required to mine at depths below the water table with conventional wheel, or track, mounted equipment. The deposits generally are characterized by very large hydraulic conductivities. At greater mining depths, rates of seepage into pits may be so large that complete dewatering, shown in Figure 1B, is not practical.

Dredging is a more useful method for mining most of Central Florida's sand deposits. Before environmental regulations were applied to sand mines, dredge mines like the one shown in Figure 1C were common. Mine and process water was used once, and simply discarded. At the time, the mining areas were very remote; and there were few neighbors to complain about releases of turbid water. The primitive dredges in use at the time were limited to relatively shallow mining depths. So dredge pumps served two purposes, mining and dewatering. Pit water levels were drawn down as low as possible, to maximize mining depths. Relatively little clear water was available in the mine pits to use for sand processing. Many mines required large production wells, called "make up" wells, to supply additional clear water, from deeper aquifers, for sand processing.

A variety of environmental liabilities can result from use of mining methods that depend upon dewatering, like those illustrated in Figures 1B and 1C. Removal of water from the mine pits draws down adjacent water table elevations, which may adversely affect nearby environmental features, like wetlands. Disposal of the water that is withdrawn from the mine pits can be problematic. Suspended solids are detrimental to the biota of natural surface water systems; so the water must be treated before disposal. And hydraulic aspects of disposal must be handled carefully, to prevent unwanted flooding. Drawdown in confined aquifers, resulting from withdrawal of make-up water from deep wells, may affect water supplies over great distances.

In Florida, water and environmental regulations are strictly enforced. Virtually all of the environmental liabilities discussed in the paragraph above can be easily avoided by recycling mine and process water. Modern dredges are designed for suction from much greater depths; so there is no need to maintain low pit water levels. Figure 1D shows how process water can be recycled in a closed-loop, to virtually eliminate water table drawdown. By treating and reusing process water there is no need for off-site discharges, and no need to withdraw make-up water from deep aquifers.

Closed-loop hydraulic dredging is the most commonly used method of mining sand in Central Florida. In a typical operation, raw sand is mined hydraulically and transported, in slurry form, to plants where additional water, withdrawn from the mine, is used to wash and size the products. Finished sand products are stacked to dry by gravity drainage. Wastewater, fine-grained tailings materials, and drainage from the stockpiles are returned to mined-out parts of pits for disposal. Recirculation of process water is an industry standard in Central Florida's sand mining industry.

Although it may appear to laymen that large volumes of water are used for sand mining and processing, it is more accurate to state that sand mines recycle water at large rates. Very little water is lost from modern closed-loop dredge mines. Interestingly, the largest losses of water are not at all related to pumping. They result from evaporation. The hot Florida sun that tourists crave when they visit our beaches, causes water to evaporate from open water bodies, including sand mine lakes, at rates that exceed rainfall.

On this field trip we will visit dry mines, like the illustration in Figure 1A, and closed-loop dredge mines, shown schematically in Figure 1D. The other mining methods are not currently used by Central Florida's sand mining industry.

Stop 1 will visit the Jahna Haines City Mine, a typical closed-loop dredge mine. Wink Winkler and Kirk Davis will describe the mining methods and shallow stratigraphy of the facility and lead a tour of the v-box processing plant. We will examine a reclaimed pit slope, where interesting sedimentary structures and in-situ fulgurites may be collected.

Stop 2 is at C.C. Calhoun's Pit #1, a relatively deep dry excavation where no dewatering is required. Thick exposures of Plio-Pleistocene sediments are visible. Kendall Fountain will give an overview of the depositional and facies characteristics of the Cypresshead Formation. Marc Hurst will present an interpretation of jointing in Northern Polk County. And Pete Adams will

present the hypothesis of karst-driven isostatic crustal uplift and the origin of Florida's marine terraces, leading to a discussion of Florida landscape evolution.

Stop 3 is at the Vulcan Sandland Mine, a closed-loop dredging operation that is currently under reclamation, as its production winds down. C.T. Williams will give a brief history of operations at the facility, an overview of traditional pit reclamation techniques, and a discussion of some more innovative plans.

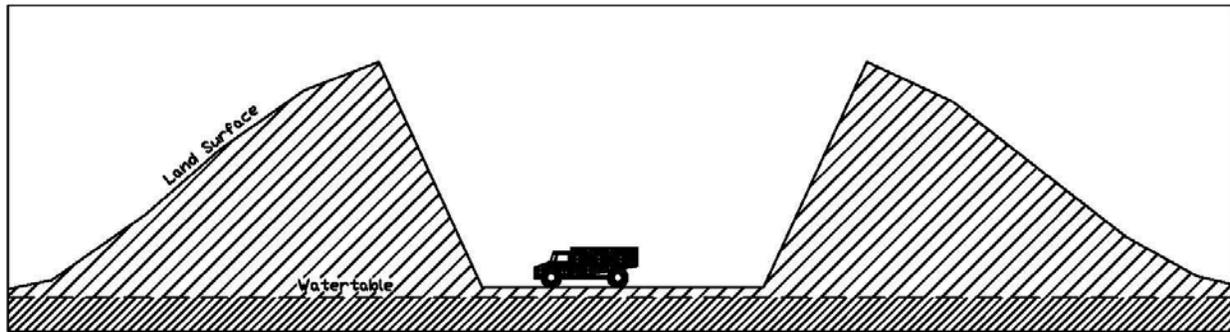
Stop 4 will visit C.C. Calhoun's Pit #7, a facility that is permitted for mining, and also as a land filling operation. Marc Hurst will give a brief presentation on land filling as a reclamation alternative for dry excavations.

As we drive between stops, imagine the primal pine forests and cypress swamps that attracted the naval stores and timber industries to the area. They were cleared out a century ago. Most of the railroad tracks that were used to transport them away are gone, too.

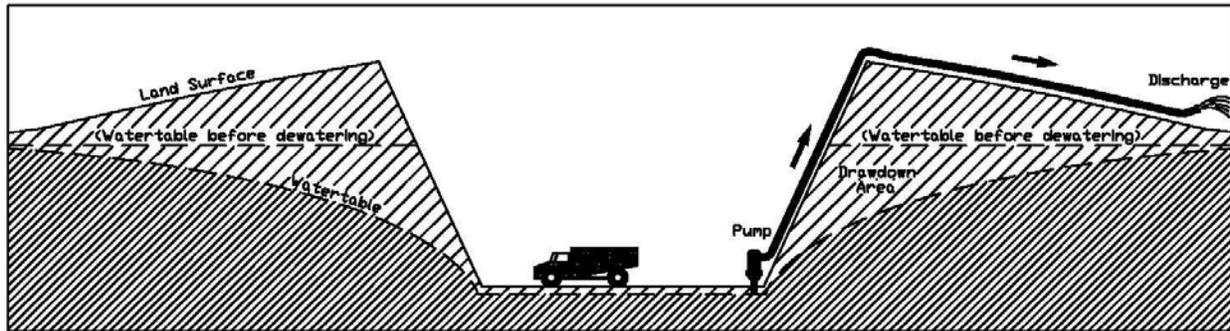
Note the citrus groves, that replaced the forests. They are remnants of an agricultural industry that covered virtually all of the Ridge until its eclipse in recent years, due to frost events, global changes in the citrus industry, introduction of plant diseases, and the increasing value of property for residential development. According to citrus experts, the remaining groves along the Ridge are notable for producing some of the world's best tasting juice, which commonly is blended with products from other regions to improve their flavors.

Also note the many new housing developments. They are a small sampling of the multitudes of similar developments, covering a range including most of peninsular Florida, that were built with raw materials from the high-grade silica sand deposits found along the Ridge.

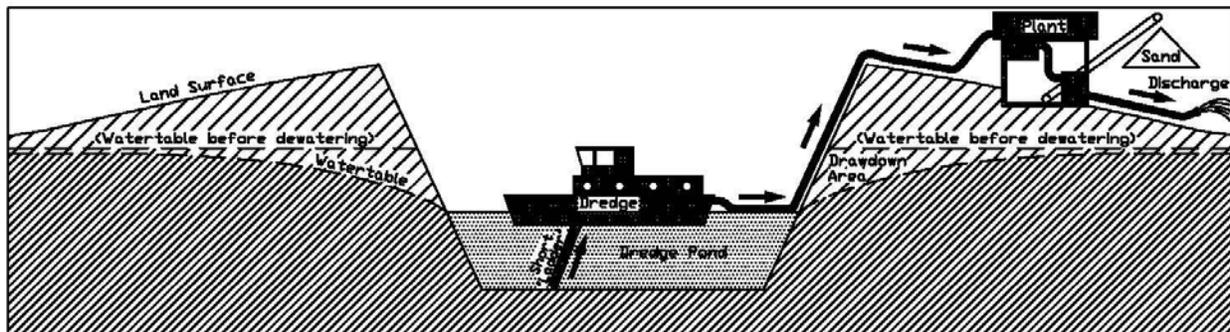
In the beginning, the Central Florida Sand Mining District was relatively remote from the development areas where its sand products were marketed. However, during the last couple of decades, the expanding market areas have grown closer and closer to the sources of raw materials. Now, development is overtaking the Ridge. It is ironic that residential construction has begun to encroach upon the region's sand reserves, and to threaten the viability of the mines that supply the raw materials for development.



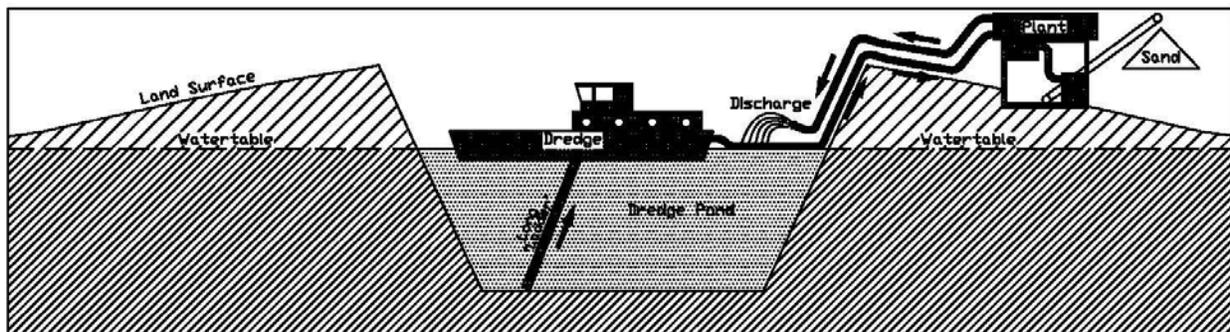
A. Dry Open-Pit Mine, No dewatering is required.  
(Pit #1 and Pit #7 are examples.)



B. Dewatered Open-Pit Mine, Water is removed from pit and discharged elsewhere.



C. Open-Loop Dredge Mine, Some water is removed and discharged elsewhere.  
(Not typically used in Central Florida)



D. Closed-Loop Dredge Mine, Water is recycled through pond and plant.  
(Method used at Haines City, Lake Wales, Sandland, and Davenport Sand Mines.)

Independent Geological Services, Inc.

July 27, 2001  
Not to Scale

Water Flow Direction  
→

Figure 1. Simplified Cross-Sections of Various Sand Mining Methods

## **SAND MINING METHODS AND SHALLOW STRATIGRAPHY AT THE E.R. JAHNA INDUSTRIES HAINES CITY SAND MINE, POLK COUNTY, FLORIDA**

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*E.R. Jahna Industries, Inc.*  
*Lake Wales, FL 33853*

### **Location and History**

The Haines City Sand Mine is located on the north side of County Road 544 approximately five miles east of US Highway 27, 3.2 miles southeast of Haines City, Florida (Figure 1). The coarse sand deposit was identified by Mr. Emil R. Jahna Jr. in the early 1970s. Mine construction followed and sand production started in 1974. The mine continues production into its fourth decade by virtue of several acquisitions of adjacent property over the years, the most recent in 2008. The current mine property encompasses 695 acres.

### **Mining and Processing**

Jahna designed and built a 500-HP suction dredge with a Georgia Iron Works 12x14x36-inch pump to transport unconsolidated sand and clayey sand to the processing plant. Typical mining depths of 30 to 50 feet are achieved with a 70-foot long dredge ladder. Slurrified sand and clay are currently pumped approximately 2,800 feet to the processing plant in 14-inch diameter high-density polyethylene (HDPE) pipe with no booster pump. The slurry initially passes over a static screen then a vibratory screen prior to flowing into an Eagle Iron Works 10-foot by 40-foot, 3 product cell, 11 station v-box classifier. Coarse concrete sand is dewatered on an Eagle twin 66-inch screw prior to being placed on the product pile via a 36-inch by 150-foot radial stacker. A GIW 8x10 LSA32, 200-hp pump is used to transport the finer masonry sand to a 26-inch hydraulic cyclone that delivers this product to a radial stacker. Fine sand (passing the No. 100 sieve) and clay tailings are discarded in the mined out pit using a 600-hp 18x18 LHD33 GIW pump through 18-inch diameter HDPE pipe. Figure 2 is an oblique photograph (looking south) of the plant and product stockpiles, with tailings disposal in the foreground and entrance road and mined out lakes in the background.

Three fine aggregate products are produced at the Haines City Mine: FDOT certified concrete sand (typical fineness modulus = 2.20), commercial concrete sand (typical FM = 2.05), and masonry sand (typical FM = 1.35). Sand products are trucked to customers for use in the production of ready mixed concrete, roof tiles, pavers, concrete block, stucco, asphalt, sand blasting materials, bagged concrete mixes, precast concrete (power poles, floor decks, lintels, walls, autoclaving and ornamental casting), filter/drainage sand, and beach renourishment sand. Our market is typically within a 40 to 70-mile radius, primarily south and west of the mine in Polk, Hillsborough, Highlands, Pinellas and Manatee Counties.

### **Geologic Setting**

The Haines City Sand Mine is located on the eastern flank of Lake Wales Ridge, the most prominent geomorphic feature on the Florida peninsula (White, 1970). This elongate ridge extends from Lake County to the north to Highlands County to the south, with elevations ranging from 70 to 312 feet (Arthur et al., 2008). Figure 3 shows the mine location, the Lake Wales

Ridge and two other prominent ridges in Polk County – the Lakeland Ridge and Winter Haven Ridge.

The Lake Wales Ridge is underlain by a thick sequence of generally fine to coarse grained Pliocene siliciclastics mapped as the Cypresshead Formation. The most recent geologic map of Florida (Scott et al., 2001) shows the Haines City Sand Mine located in an area mapped as Reworked Cypresshead Formation (TQuc), east of a narrow north-south band of Cypresshead Formation (Tc) along the crest of the Lake Wales Ridge (Figure 4). The relatively sharp topographic relief along the eastern side of the Lake Wales ridge is likely due to relatively high-energy reworking during the late Pliocene and Pleistocene (Arthur et al., 2008). In the area of the Haines city Mine, Cypresshead Formation sands are underlain by Miocene Hawthorn Group strata.

### **Mine Stratigraphy**

Fine to coarse sands and clayey sands (with occasional discoid pebbles) of the Reworked Cypresshead Formation (TQuc) and/or Cypresshead Formation (Tc) are the ore zone at the Haines City Sand Mine. Mineable sand extends from land surface to depths ranging from 30 to 50 feet. Dredging typically terminates in fine to very fine white clayey sands.

The prospect log summary for hole 174 is included in Figure 5 to illustrate the shallow stratigraphy at the mine. The prospect log is typical of recent descriptions of reverse-air drilling conducted by Jahna to evaluate the extent and quality of sand reserves at the mine. Medium to coarse sands extend to only 25 feet in this boring, with a thick sequence of unmineable fine clayey sands extending to a depth of 69 feet. The boring encountered an interval of medium to coarse sands from 65 to 69 feet, and terminated on limerock at a depth of 69 feet; elevation +39 feet MSL.

The pre-mining landuse for most areas of the Haines City Mine is citrus groves. In advance of mining, large diameter irrigation wells that penetrate the Floridan aquifer system are typically abandoned and grouted. As part of this effort, the Southwest Florida Water Management District completed a geophysical log in 2002 on a citrus irrigation well located on the east side of the mine identified as 20-1069. The geophysical data indicate a significant increase in gamma ray counts ranging from 100 to over 300 cps beginning at a depth of 75 feet and extending to about 185 feet. These relatively high gamma counts are caused by the clayey, phosphatic Hawthorn Group sediments that contain trace amounts of Uranium. The dramatic increase in gamma response is at an elevation of +35 feet MSL, at approximately the same elevation recorded as limestone in prospect boring 174.

### **Trace Fossils**

The Cypresshead Formation is typically lacking in original fossil material, but it occasionally contains poorly preserved casts and molds of mollusks, and burrow structures (Scott et al., 2001). The tracemaker organism, probably a callianassid shrimp, was found to prefer the margins of channels in nearshore marine environments (Miller, 1998). During periodic lowering of the pit water level due to operations and/or climactic drought, a layer with relatively abundant trace fossil *Ophiomorpha nodosa* has been exposed in the mine at about elevation +75 feet MSL. Figure 6 includes a photograph of three *Ophiomorpha nodosa* collected at the mine. Similar

burrow structures have been found on the east side of the Lake Wales Ridge at Jahna's Clermont East Mine, and south of the Lake Wales Ridge at Ortona. However, these trace fossils have not been observed at the Jahna Green Bay or 474 Independent mines on the west side of the Lake Wales Ridge.

### **Fulgurites**

A fulgurite is an irregular, glassy, often tubular or rod-like structure of fused sand that was melted by a lightning strike (the melting point of SiO<sub>2</sub> is 2,950°F). Based on the intensity of the lightning strike and the nature of the subsurface materials, fulgurites can be quite long. In 1997, University of Florida engineering researchers excavated a 17-foot long fulgurite from a recent lightning strike at Camp Blanding, Florida. Recent reclamation grading along the east mine boundary has exposed a significant layer of fulgurites extending from the land surface to depths of about 25 feet. Fulgurites at the Haines City Mine are typically 0.25 to 1 inch in diameter and are typically found in broken sections 1 to 6 inches in length. At least three types of fulgurites have been identified at the mine by Davis; soda straw, collapsed and heavy melt. An example of each fulgurite type is included in the Figure 7 photograph.

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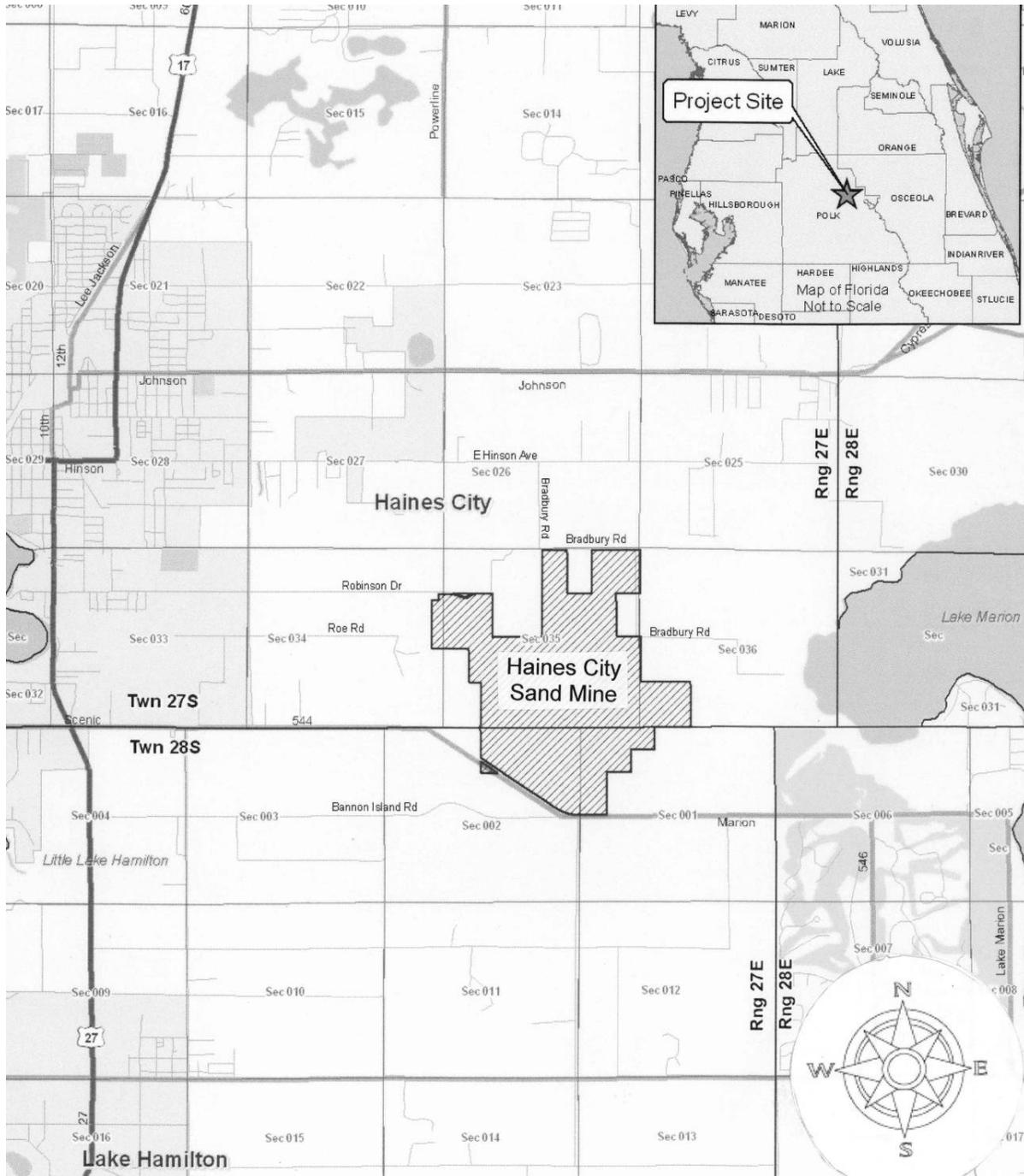
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**Figure 1. Location Map – Haines City Sand Mine  
Approximate Scale: 1 Inch = 0.9 Miles**



Figure 2. Oblique photograph of the Haines City Sand Mine Plant Site

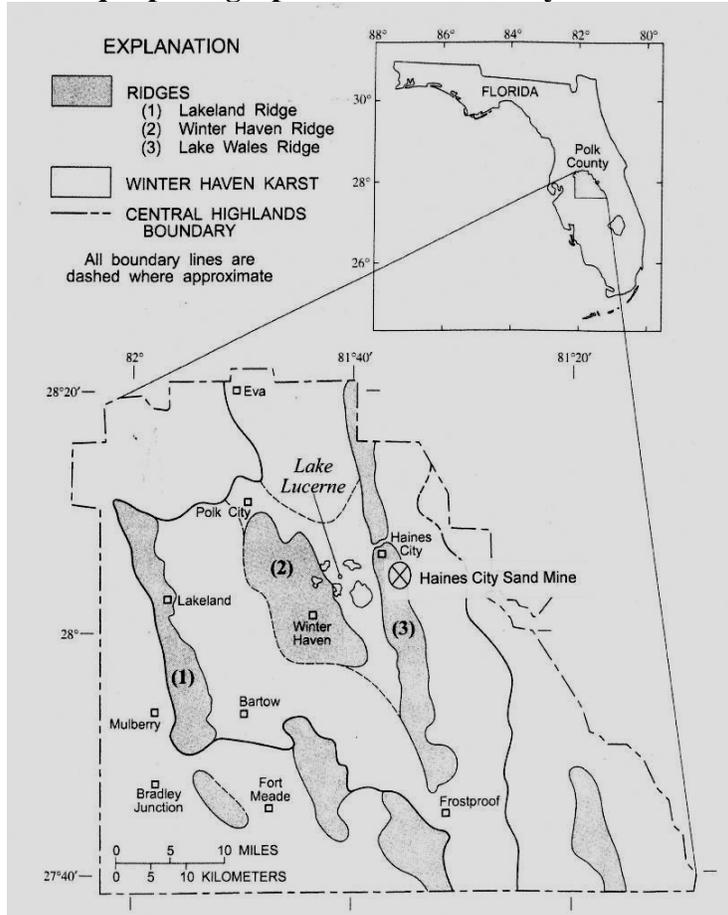
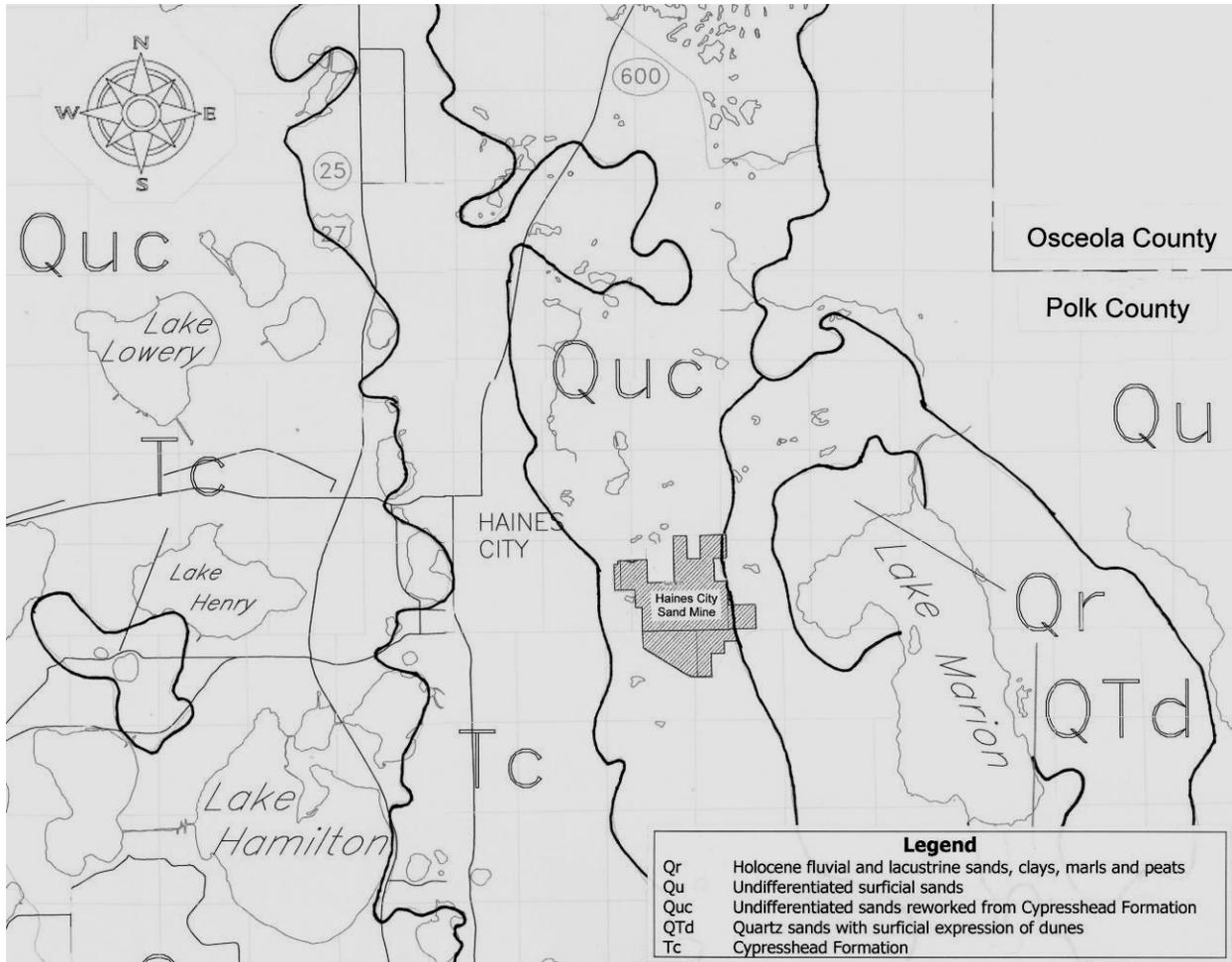


Figure 3. Polk County Ridges with Haines City Mine (modified after Lee & Swancar, 1997)



**Figure 4. Haines City Sand Mine Location on Geologic Map (Scott et al., 2001)**  
**Approximate Scale: 1 Inch = 2.1 Miles**

<b>Prospect Log Summary</b>		E.R. Jahna Industries 202 East Stuart Avenue Lake Wales, FL 33853		
Property Name	<b>Liberty Bluff</b>	Hole Number	<b>174</b>	
Landowner	<b>E.R. Jahna</b>	Total Depth (feet)	<b>69</b>	
County	<b>Polk</b>	Date (s) Drilled	<b>16-Nov-09</b>	
State	<b>FL</b>	Waypoint ID	<b>174</b>	
Section	<b>35</b>	Township	<b>27</b>	Range <b>27</b> Elevation (feet) <b>108</b>
<b>Interval (Feet)</b>	<b>Lithologic Description</b>			
<b>0 to 5</b>	<b>Grayish Orange 10YR 7/4 Fine to Sl. Coarse Sand</b>			
<b>5 to 10</b>	<b>Same as Above</b>			
<b>10 to 15</b>	<b>Pale Yellowish Brown 10YR 6/2 &amp; Grayish Orange 10YR 7/4 Fine to Sl. Coarse w/Trace of Very Coarse Sand</b>			
<b>15 to 20</b>	<b>Grayish Yellow 5Y 8/4 Med to Sl. Coarse w/Trace of Very Coarse Sand</b>			
<b>20 to 25</b>	<b>Yellowish Gray 5Y 7/2 Med to Coarse w/Trace of Very Coarse Sand</b>			
<b>25 to 30</b>	<b>Yellowish Gray 5Y 7/2 Very Fine Sand &amp; Soft Clay</b>			
<b>30 to 35</b>	<b>Yellowish Gray 5Y 8/1 Very Fine Sand &amp; Soft Clay</b>			
<b>35 to 40</b>	<b>Same as Above</b>			
<b>40 to 45</b>	<b>Pale Greenish Yellow 10Y 8/2 Very Fine Sand &amp; Soft Clay</b>			
<b>45 to 50</b>	<b>Same as Above</b>			
<b>50 to 55</b>	<b>Yellowish Gray 5Y 8/1 Very Fine to Fine Sand &amp; Soft Clay</b>			
<b>55 to 60</b>	<b>White N9 Very Fine to Fine Sand &amp; Soft Clay</b>			
<b>60 to 65</b>	<b>Pale Olive 10Y 6/2 to Pale Greenish Yellow Very Fine to Very Coarse Sand &amp; Stiff Clay</b>			
<b>65 To 69</b>	<b>Pale Greenish Yellow 10Y 8/2 Very Fine to Fine w/Trace of Med to Coarse Sand, Trace of Pebbles</b>			
	<b>Hit Limerock at 69 Feet</b>			
Drilled by:	<b>Jahna</b>	Drill Method:	<b>Reverse Air</b>	Water Table (ft) <b>28</b>
Driller / Helper:	<b>David/Tim</b>	Composite Depth (feet)	<b>0-69</b>	Latitude (N): <b>28°5.389'</b>
Logged by:	<b>Tim</b>	5-Foot Samples (feet)	<b>0-69</b>	Longitude (W): <b>81°35.181'</b>
Remarks:			Sheet:	<b>1 of 1</b>

Figure 5. Prospect Log Summary, Hole No. 174



**Figure 6. Photograph of *Ophiomorpha nodosa***



**Figure 7. Photograph of Fulgurites.  
Left to right: soda straw, collapsed, heavy melt.**

## **DEPOSITIONAL AND FACIES CHARACTERISTICS OF THE CYPRESSHEAD FORMATION IN NORTH-CENTRAL FLORIDA**

Kendall B. Fountain

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### **Introduction**

The name Cypresshead Formation was first used by Huddlestun (1988) to describe “a prominently thin- to thick-bedded and massive, planar- to cross-bedded, variably burrowed and bioturbated, fine-grained to pebbly, coarse-grained sand formation in the terrace region of eastern Georgia”. Subsequently, the name was extended into Florida by Scott (1988) to encompass sediments in peninsular Florida previously assigned to the Citronelle Formation of Matson (1916). As defined by Huddlestun (1988) and Scott (1988), the Cypresshead Formation is composed entirely of siliciclastics; predominately quartz and clay minerals, with quartz and/or quartzite pebbles locally abundant (Pirkle et al., 1970). The formation has been variously described as Miocene to Pleistocene in age (Puri and Vernon, 1964; Scott, 1988), and originating either through fluvial-deltaic processes (Bishop, 1956; Pirkle, 1960; Pirkle et al., 1964; Klein et al., 1964; Peacock, 1983; Cunningham et al., 2003) or *via* longshore current transport and deposition in a nearshore, marine to brackish environment (Bell, 1924; Martens, 1928; Alt, 1974; Winker and Howard, 1977; Peck et al., 1979; Kane, 1984; Huddlestun, 1988; Scott, 1988). The latter of these issues, focusing on the depositional characteristics of the unit, is the focus of this paper. Figure 1 illustrates the localities evaluated in this study.

### **Sedimentary Structures**

A variety of environment and process sensitive sedimentary structures are associated with Cypresshead Formation sediments. Included among these are various types of stratification and bedforms, discontinuity surfaces and trace fossils.

### **Stratification and Bedforms**

Several forms of stratification indicative of depositional environment are well preserved in Cypresshead sediments. The first of these, cross-stratification, has been described by Kane (1984), and consists of three principle types; tabular, trough and hummocky. Tabular cross-stratification is small to large in scale, ranging from 5 cm to 3 m in bed thickness, with foreset dips generally in the 20-25° range (Figure 2A and B). Cross-strata are generally symmetrical, with angular to tangential lower bounding surface contacts consistent with formation by the migration of straight-crested sand waves and dunes (megaripples). The smaller of these features (5-60 cm) are concentrated near the top of the sections where they are present, but may occur sporadically near the base as well. Larger features (0.5-3 m) have been noted in north-central Florida at the Grandin and Goldhead Mines, and are consistent with the migration of dune or megaripple bedforms associated with nearshore bars (Figure 2B).

Trough cross-stratification is small to medium in scale, ranging from 5 cm to 60 cm in bed thickness, with foreset dips in the same range as seen with tabular cross-strata (Figure 2A). Cross-strata are lenticular and asymmetrical, and exhibit tangential contacts with erosional

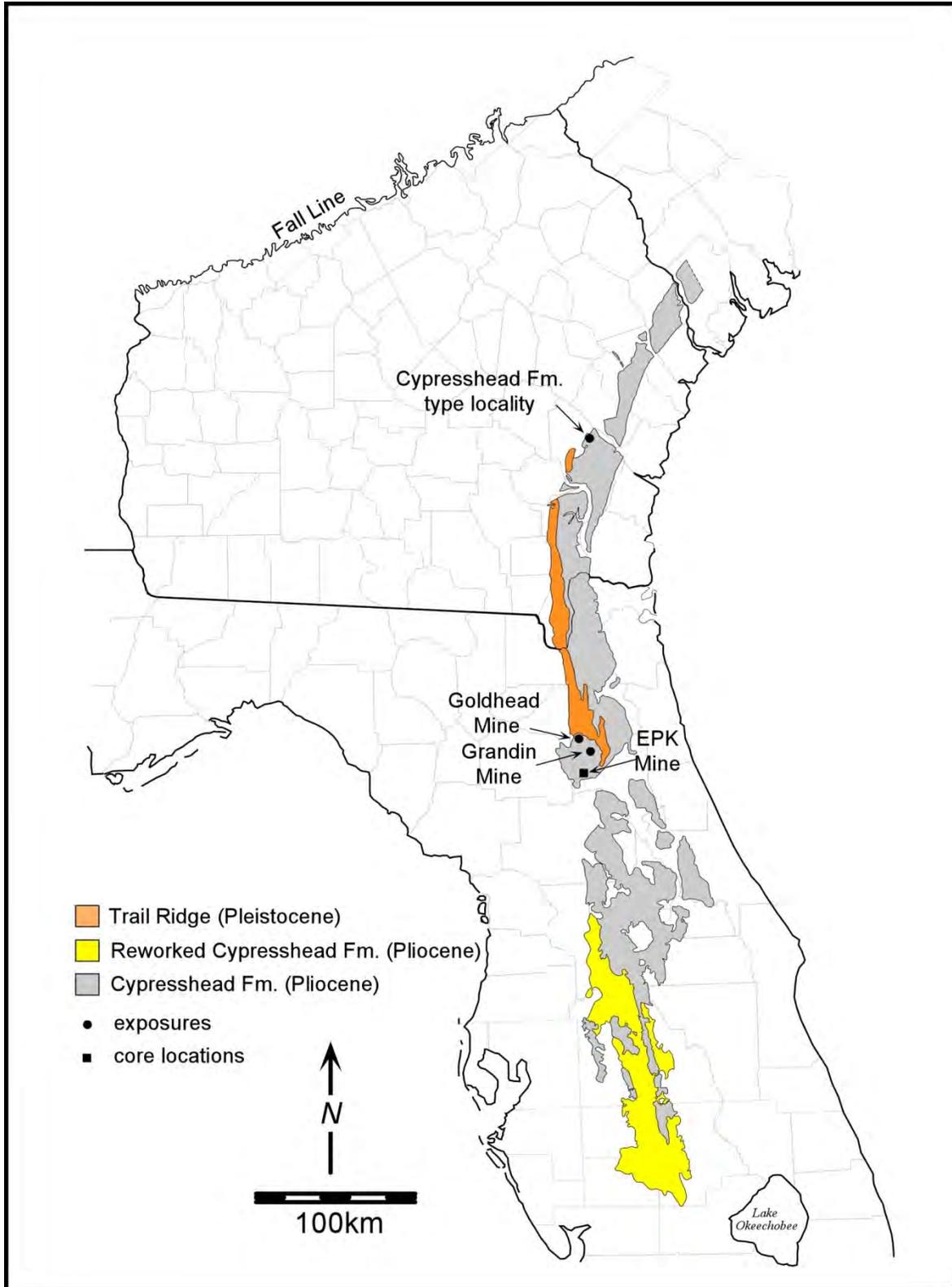


Figure 1. Distribution of the Cypresshead Formation in Florida and southeastern Georgia (modified after Huddleston, 1988; Scott et al., 2001).

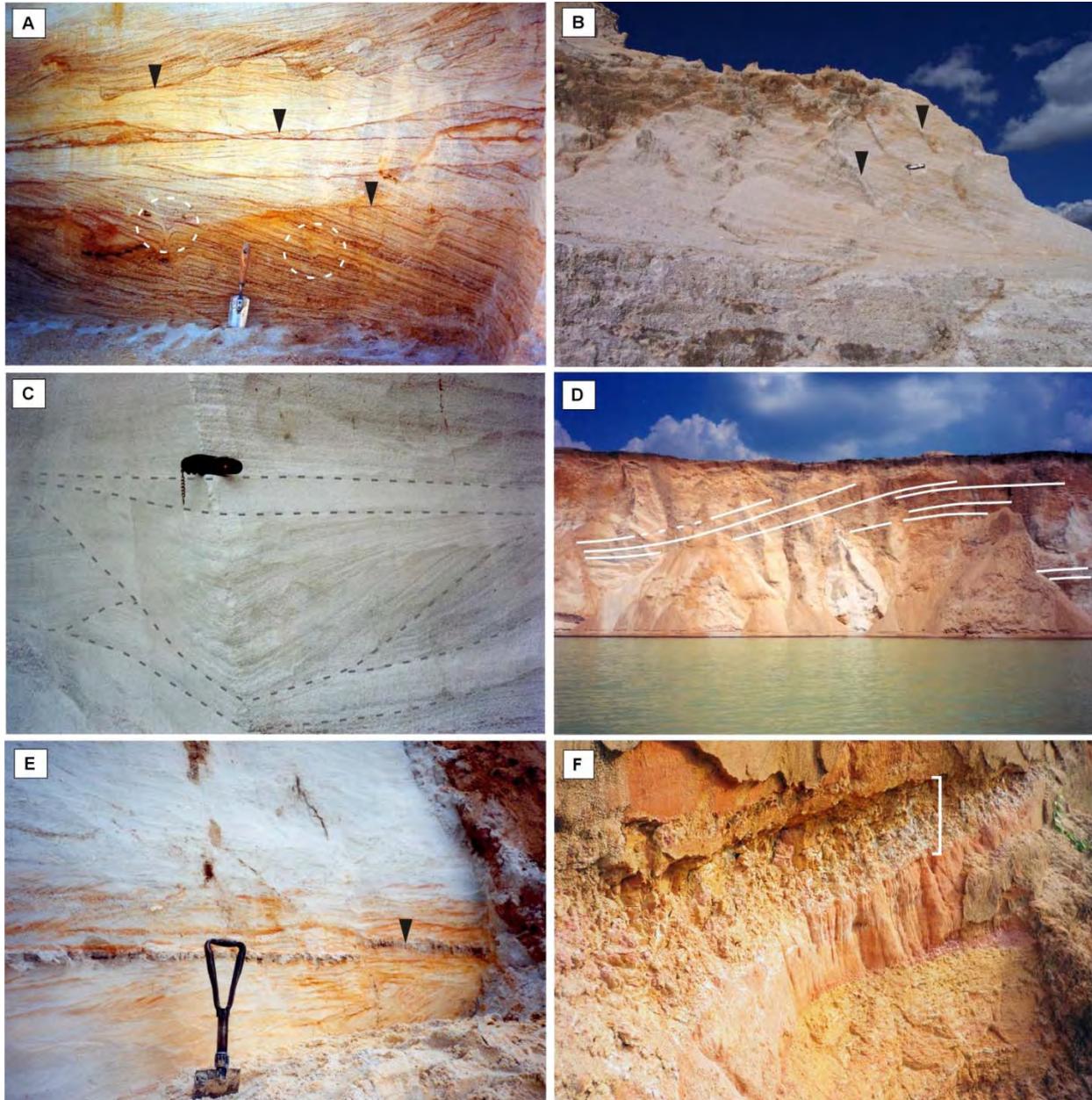


Figure 2. Example sedimentary structures from exposures of the Cypresshead Formation in north-central Florida and southeastern Georgia. A) Tabular and trough cross-bedding exposed at the Grandin Mine, illustrating scour and fill and horizontal bedding surfaces (arrows) along with escape structures (circles), B) Large-scale tabular cross-bedding associated with the migration of dune or megaripple bedforms, containing 0.5-1 m long *Ophiomorpha* spp. burrows (arrows) inclined in response to current activity (Grandin Mine), C) Hummocky cross-stratification from basal exposures at the Grandin Mine, D) Large-scale infilling of a nearshore channel (Grandin Mine), E) Clay lense nondepositional discontinuity (arrow) from Linden Bluff near the Altamaha River in southeastern Georgia (offset due to slumping along exposure face), F) Clay bed nondepositional discontinuity (bracket) from the Cypresshead Formation type locality near Jesup, Georgia.

lower bounding surfaces consistent with formation by the migration of undulatory and lunate sand waves. Graded bedding within individual bed sets is common. As was noted for tabular cross-strata, these features are concentrated near the top of most sections, with a less common and more sporadic distribution with increased depth. Scour and fill structures are commonly associated with this type of cross-stratification, suggesting significant flow velocities. Large-scale scoured surfaces with up to 15 m in vertical relief, likely representative of nearshore current or tidal channels, are also evident in limited Cypresshead exposures in north-central Florida (Figure 2D).

Hummocky cross-stratification, unnoticed by Kane (1984), has been observed in the basal fine sands exposed at the Grandin Mine. These cross-strata are medium in scale, ranging from 0.3 m to 1 m in bed thickness, with foreset dips and truncation angles  $< 15^\circ$  (Figure 2C). As was noted for trough cross-stratification, cross-strata form tangential contacts along erosional lower bounding surfaces. Diagnostic traits which differentiate these beds from other forms of cross-stratification are the antiformal hummocks and synformal swales which are defined by randomly oriented, even lamination (Dott and Bourgeois, 1982). Hummocky cross-stratification is most commonly associated with redeposition of fine sand below normal fair-weather wave base by large waves.

A second form of stratification noted in Cypresshead sediments is horizontal, and sometimes massive, bedding. Where noted, horizontal bedding is more concentrated at the base of exposures, and appears to be consistent with deposition under low flow velocity conditions insufficient to develop ripple or larger bedforms. Graded bedding within horizontally bedded strata is also common. Massively bedded Cypresshead strata appear to result from the destruction of original sedimentary fabric through bioturbation, or in some cases, weathering. These beds tend to be concentrated near the top of exposures where weathering is strongest, or in association with other bioturbated beds which have retained evidence of original stratification.

### **Discontinuity Surfaces**

Two types of stratigraphic discontinuities are recognized in Cypresshead siliciclastics; nondepositional and erosional. The first of these, nondepositional discontinuities, mark abrupt decreases in sediment accumulation rates and are commonly associated with increased concentrations of burrowing activity or the deposition of discrete clay lenses or beds (Figure 2E and F). Erosional discontinuities are more common in Cypresshead sediments, and mark an abrupt increase in sediment accumulation, grain-size (e.g. graded bedding) and corresponding erosive scouring, either by currents or waves. These features are particularly pronounced at the base of medium to large-scale planar cross-stratification associated with dune (or megaripple) bedforms (Figure 2B).

### **Trace fossils**

Kane (1984) summarized the occurrence of *Ophiomorpha* spp. trace fossils, bivalve molds and fecal pellets as the sum fossil assemblage associated with the Cypresshead Formation. However, a more careful evaluation of exposures in Florida indicate a slightly more diverse assemblage than previously described. *Ophiomorpha* spp. burrows, normally consistent with *Ophiomorpha nodosa*, are the most common trace fossil in Florida, and are typically 3-4 cm in diameter and can exceed 1 m in length (Figures 2B and 3). Specimens retain a characteristic knobby exterior

and may exhibit minimal branching oriented at an oblique angle to bedding. In most instances, *Ophiomorpha* spp. burrows are vertically oriented and non-branching although occasionally burrows may be inclined in response to strong current conditions during coeval deposition and burrowing activity. Burrows stand out in relief, consisting of clay cemented sands more resistant than the surrounding sediments. Where sediment clay contents are low, escape structures are common. Burrows are normally sand filled with rare instances of kaolinite replaced fecal remains preserved in the base. Along the modern Florida and Georgia coastlines, *Callianassa major* (ghost shrimp) burrows are considered to be a modern analog, and are accepted as shoreline indicators. Although they primarily occur in the sandy, open marine littoral to shallow neritic environment, they have been reported on protected beaches, sandy tidal flats, and shoals (Frey, 1970), tidal deltas (Warme, 1971), and offshore bars (Weimer and Hoyt, 1964).

*Thalassinoides* spp. burrows observed in north-central Florida basal Cypresshead sediments are often similar in size and appearance to *Ophiomorpha* spp. burrows, but occur in units consisting of fine sand with greater clay contents, have greater developed horizontal branching, and lack a knobby exterior (Figure 3C). Differences in structure likely reflect differences in the substrate in which the burrow was constructed. *Thalassinoides* spp. burrows commonly exhibit secondary boring of shaft walls and backfilled burrow interiors, producing a trace which is similar in appearance to traces observed in the Grandin Mine and assigned to *Skolithos* spp. *Skolithos* spp. traces are commonly associated with both *Ophiomorpha* spp. and *Thalassinoides* spp. burrows, and have been described by Chamberlain (1978) as any simple, even width vertical tube varying in diameter from 2mm to 10 mm, with walls which are usually smooth, but may be segmented or striated. In the study area, these tubes range in diameter from 2mm to 5 mm and possess burrow walls formed from agglutinated sand grains. Polychaete (annelid) worms are likely responsible for these structures, and are indicative of a marginal marine facies (Seilacher, 1967). Along the Georgia Sea Isles coast, analogous tubes associated with the polychaete species *Onuphis microcephala* often occur in association with *Callianassa major* burrows (Curran, 1985). Environmentally, *Skolithos* spp. traces appear consistent with burrowing activity during periods of quiescent to highly reduced sedimentation. Additionally, the low biodiversity exhibited by this trace fossil assemblage is consistent with a high stress environment associated with episodic high sedimentation rates dictated by fluctuating, but often high, current flow velocities.

The last fossils of note which have been described in detail by Kane (1984) are clay (kaolin) molds of marine bivalves similar in morphology to the modern surf clam *Mercenaria* spp. and the razor clam *Ensis* spp. Readily visible in horizontal exposures at the north-central Florida Paran Church site adjacent to the Grandin Mine, these molds represent disarticulated valves which appear to have been transported by current and/or tidal activity from a proximal estuarine source (Figure 3D). Preservation is poor, with stratigraphic positioning of the fossils in basal Cypresshead sediments potentially favored by the relatively high clay content of the fine sands.

### **Facies Architecture**

Pirkle (1960), Kane (1984) and Huddlestun (1988) have made past attempts at describing the lithofacies which compose the Cypresshead Formation in north-central Florida and Georgia based primarily on field observations. In this paper, information from field observations were combined with a detailed evaluation of the sedimentary framework of the unit to arrive at the



Figure 3. Examples of trace fossil and bivalve mold occurrences. A) Densely bioturbated sample interval from the Grandin Mine, B) Close-up of interval illustrated in (A) showing the morphology of *Ophiomorpha* spp. (left arrow) and *Skolithos* spp. (right arrow) traces, C) *Thalassinoides* spp. burrows from the Paran Church site exhibiting secondary burrowing of shaft walls and burrow interiors, D) Fossil bivalve molds from the Paran Church locality.

facies outlined in Table 1. The distribution of stratigraphic discontinuities was then used to define facies boundaries and corresponding facies architecture for north-central Florida as shown in Figure 4.

In north-central Florida, a total of five facies were identified based on sedimentological factors which define a single coarsening-upward cycle consistent with the progradational siliciclastic deposition of a shoreface-shelf parasequence. Included with these facies is the Nashua Formation of Huddlestun (1988), which has been previously defined by both Huddlestun (1988) and Scott (1992) as an offshore facies of the Cypresshead Formation in both north-central Florida and southeastern Georgia. For the purpose of this study, the Nashua is assigned to the offshore inner shelf (OSI) facies and defines the basal facies unit of the Cypresshead Formation for both north-central Florida and southeastern Georgia.

Table 1. Facies summary of the Cypresshead Formation in north-central peninsular Florida and southeastern Georgia.

Facies	Lithology	Sedimentary structures	Bioturbation
<i>North-central Florida</i>			
Upper shoreface (USF)	Quartz sand, medium to coarse, with minor gravel throughout. Sand is slightly clayey to clayey near the top due to illuviation	Tabular and trough cross-bedding (10-60 cm) dominant except where bioturbation or weathering has destroyed primary sedimentary structure (massive bedding)	Dense to sparse, consisting of <i>Ophiomorpha</i> spp., <i>Skolithos</i> spp. and undiff. traces with escape structures
Proximal lower shoreface (pLSF)	Quartz sand, medium to coarse, with gravel throughout. Sand is slightly clayey, with clay more common as stringers and lenses.	Trough cross-bedding (10-40 cm) transitions into 0.5-3 m tabular cross-bedding associated with the migration of dune (megaripple) bedforms	Dense near top, consisting of <i>Ophiomorpha</i> spp. and <i>Skolithos</i> spp. traces
Distal lower shoreface (dLSF)	Quartz sand, medium to fine, with interbedded coarse sand and gravel. Sand is slightly to moderately clayey. Minor feldspar (<5%) and mica	Horizontal bedding with 10-40 cm trough cross-bedding interbedded with 0.3-1 m hummocky stratification and storm derived coarse sand and gravel graded beds	Minor bioturbation consisting of <i>Thalassinoides</i> spp. and <i>Skolithos</i> spp. traces
Offshore transition (OST)	Quartz sand, medium to fine, is the dominant lithic component. Sand is clayey, with up to 20% or more clay. Minor feldspar (< 10%) and mica	Horizontal to massive bedding is dominant	unknown
Offshore inner shelf (OSI)*	Quartz sand, medium to fine, is the dominant lithic component. Sand is fossiliferous, variably calcareous, and sometimes clayey. Mollusks are the dominant fossil type	Massive bedding which appears to be devoid of primary sedimentary or biogenic structures	unknown
<i>Southeastern Georgia</i>			
Proximal lower shoreface (pLSF)	Quartz sand, medium to coarse, with minor gravel throughout. Sand is slightly clayey to clayey near the top due to illuviation. Clay common as stringers and lenses.	Tabular and trough cross-bedding (10-60 cm) dominant except where weathering has destroyed primary sedimentary structure (massive bedding)	Moderate to sparse near top, consisting of undiff. traces
Distal lower shoreface (dLSF)	Quartz sand, medium to fine, with interbedded coarse sand and gravel. Sand is moderately clayey. Minor mica	Horizontal to massive bedding is dominant	Minor bioturbation consisting of <i>Ophiomorpha</i> spp. traces
Offshore transition (OST)	Quartz sand, fine, is the dominant lithic component. Sand is clayey, with up to 30% or more clay. Clay common as stringers and partings. Minor mica	Horizontal to massive bedding is dominant	Moderate to sparse bioturbation, consisting of undiff. traces
Offshore inner shelf (OSI)*	Quartz sand, medium to fine, is the dominant lithic component. Sand is fossiliferous, variably calcareous, and sometimes clayey. Mollusks are the dominant fossil type	Massive bedding which appears to be devoid of primary sedimentary or biogenic structures	unknown

\*Corresponds to the Nashua Formation of Huddlestun (1988) and Scott (1992), which is considered a facies of the Cypresshead Formation for this study.

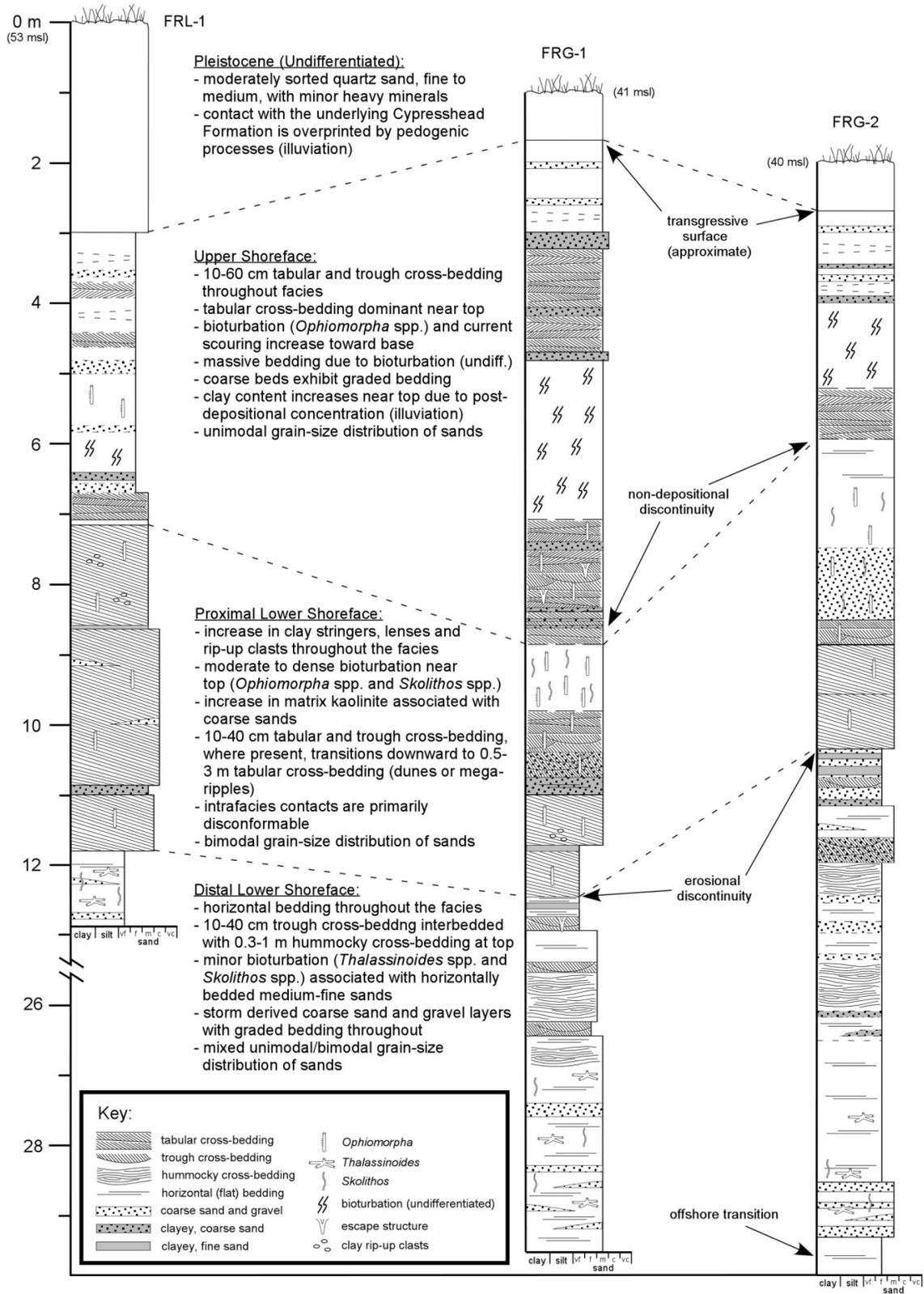


Figure 4. Correlation of Cypresshead Formation facies in north-central Florida based on sections evaluated at the Grandin (FRG-1 and FRG-2) and Goldhead (FRL-1) Mines.

Continuing upsequence, the second facies identified in north-central Florida is an offshore transition (OST) facies for which only a small section may be exposed at the base of the Grandin Mine (Figure 4). Based on sedimentological factors such as total clay and mica content, apparent horizontal to massive bedding characteristics, and a downdip position of the EPK Mine's kaolinitic sand orebody relative to the Grandin Mine, a transitional offshore environment is likely. General characteristics of the OST facies include quartz sand in the medium to fine mean grain-size range, with a minor coarse sand component and up to 20% or more clay ( $< 2 \mu\text{m}$ ) content. In north-central Florida, the clay content of this facies occurs primarily as a binding matrix. Additionally, as much as 10% of the sand fraction may consist of feldspar and/or mica, with both phases concentrated in the medium and fine sand fraction.

The third facies, identified as a distal lower shoreface (dLSF) facies, is characterized by medium- to fine-grained quartz sands which commonly exhibit hummocky cross-stratification, and are interbedded with graded and trough cross-bedded storm-derived coarse sands with minor gravel (Figures 4 and 5A). Bioturbation associated with this facies is sparse, and is dominated by *Thalassinoides* spp. and *Skolithos* spp. traces. Clay content of the dLSF facies can be as much as 10% or more in the medium to fine sand component where it occurs as a binding matrix. Additionally, minor mica and/or feldspar are common, and may represent up to 5% or more of the sand fraction, the mica content being primarily a function of hydrodynamic sorting while the feldspar content is most likely related to preservation relative to weathering. Lastly, grain-size distributions for this facies are mainly unimodal, consistent with deposition below normal wave base (Balsillie, 1995).

The proximal lower shoreface (pLSF) facies is well developed in north-central Florida mine exposures due in no small part to the relative concentration of coarse sands associated with large- to medium-scale tabular cross-stratification in this environment (Figures 4 and 5B). This facies is characterized by an increase in quartz sand grain-size (medium to coarse) with commonly associated gravel, a reduction in the overall clay content except for the occurrence of discrete clay lenses and stringers, and the extensive development of cross-stratification. The base of the facies is defined by an erosional disconformity which indicates a significant increase in scouring and sediment transport velocity. During periods of reduced current flow, clay stringers and lenses could have developed in response to quiescent conditions, with reactivation of current activity corresponding to the incorporation of clay rip-up clasts in overlying sediments. Based on the bimodal character of grain-size distributions for the pLSF facies, energies associated with current sorting and transport were mixed with wave, and possibly tidal, influences. Additionally, the top of this facies commonly exhibits dense bioturbation associated with *Ophiomorpha* spp. and *Skolithos* spp. traces (Figure 5A), marking a non-depositional discontinuity between the pLSF facies and the overlying facies.

The last facies, the upper shoreface (USF) facies, is characterized by medium to coarse quartz sands with minor gravel, which exhibit well developed small- to medium-scale tabular and trough cross-stratification consistent with a southerly directed wave and current flow orientation (Figure 5A). Many coarse beds exhibit graded bedding, and bioturbation varies from dense to sparse, dominated by *Ophiomorpha* spp., *Skolithos* spp. and undifferentiated traces. Additionally, sands are generally slightly clayey, except near the top of exposures where illuviation has resulted in the post-depositional concentration of clays.

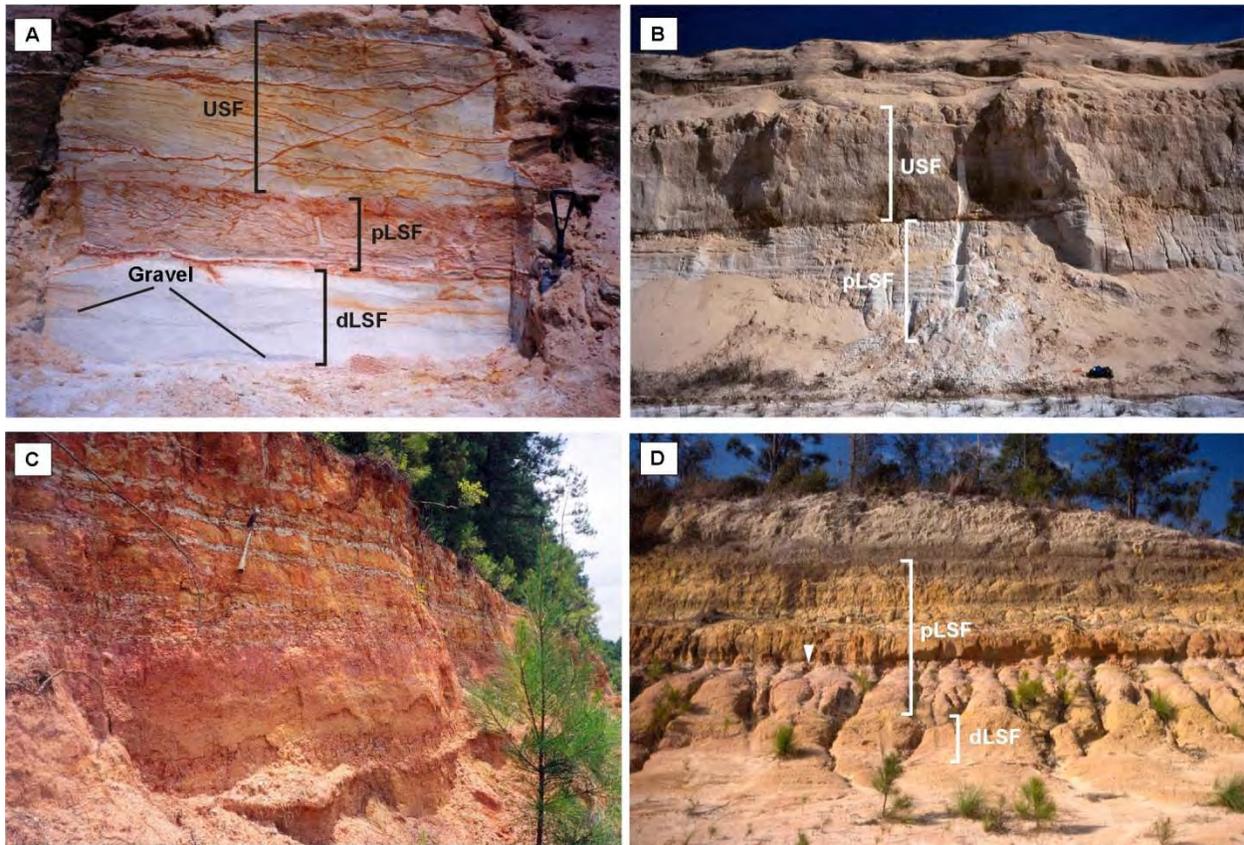


Figure 5. Examples of Cypresshead Formation facies. A) Exposure (~ 2 m) in the Grandin Sand Mine illustrating the vertical juxtaposition of dLSF, pLSF and USF facies (large-scale tabular cross-stratification is not developed in this section), B) FRL-1 exposure (~ 13 m) exhibiting well developed tabular cross-stratification associated with the pLSF facies, C) Upper portion of the B-1 exposure (~ 2.5 m) illustrating the OST facies, D) J-1 exposure (~ 5.5 m) illustrating an example of the dLSF and pLSF facies, with the J-1-4 clay bed (arrow) indicated for reference.

### **Cypresshead Formation Depositional Model**

Based on the collective sedimentological characteristics outlined for the Cypresshead Formation in north-central Florida, the unit was deposited in a wave-dominated nearshore marine setting as a shoreface-shelf parasequence, with deposition taking place in response to relative sea-level fall, resulting in a single coarsening-upward cycle of siliciclastics. Internally within the unit, this model for deposition is expressed by the presence of clinof orm surfaces that dip gently at 2-3° to the east in northern-central Florida. The most likely nearshore marine environment for Cypresshead deposition appears consistent with a strand plain setting, lacking well-developed lagoons or marshes.

In north-central Florida, the Cypresshead Formation thins toward the west onto the flanks of the Ocala Platform where it is absent (Scott, 1988). Thus, the Ocala Platform acts as a depositional basin divide between the Cypresshead Formation to the east and the time equivalent Miccosuckee and Citronelle Formations to the west. Deposition of the Cypresshead would have commenced during a sea-level highstand, with the westernmost, updip extent of the unit in close

proximity to the present location of Trail Ridge. Subsequent deposition in north-central Florida would have been dictated by regressing sea-level, sediment supply, current positioning, and available accommodation. In north-central Florida, the latter of these would have been related to antecedent topography developed on top of Hawthorn Group (Coosawhatchee Formation) sediments. Dictating available accommodation for Cypresshead siliciclastics, this surface is known to have been scoured by pre-Cypresshead erosion and submarine current activity (Cunningham et al., 2003), creating irregularities which would have acted as preferred nearshore conduits for siliciclastic transportation by longshore current and storm activity, or topographic lows for the preferential deposition of hydrodynamically sorted fines (e.g. clays and mica).

As indicated by the well developed cross-stratification and overall grain-size of Cypresshead siliciclastics, strong longshore current activity, significantly greater than seen along the modern Florida and southeastern Georgia coasts, is proposed as a major factor in the coast parallel transportation of these sediments. Evidence for similar processes extending down the Florida peninsula are noted from an outcrop described by Johnson (1989) from Lady Lake pit in Lake County, Florida, which contains two cross-bedded, coarse-grained sand beds (Beds 3 and 4), four and three feet thick, which appear to be similar to the dune (or megaripple) bedforms described in this paper. In fact, estimates by Kane (1984) for current velocities based on the maximum grain-sizes and sedimentary structures noted in Cypresshead sediments indicate values of 40–70+ cm/sec, which are consistent with strong longshore current activity capable of transporting even the largest fraction (i.e., discoid quartzite pebbles) noted for the Cypresshead. As indicated by Dobkins and Folk (1970), the development of a discoid pebble shape, as seen in Cypresshead sediments, is consistent with a high wave-energy shoreface environment. Under such conditions, the discoid (oblate) shape can be generated through abrasion as pebbles slide back and forth over sand or smaller pebbles in the surf zone. Although Pirkle et al. (1964) and others have argued against using the shape of quartzite pebbles solely as an indicator of depositional environment, noting that some component of shape is likely influenced by the inherited textural and structural characteristics, the proposed current velocities of Kane (1984) help to explain their occurrence in Cypresshead sediments.

Based on facies characteristics discussed in this study (e.g., dLSF gravels and hummocky cross-stratification), storm-induced sedimentation appears to have played a significant role in deposition of Cypresshead sediments as well. Hummocky cross-stratification in the lower portion of the Grandin Mine exposures supports this view for significant levels of storm activity, as it occurs in repetitive successions separated by horizontally bedded clayey fine sands. The hummocky beds themselves are relatively devoid of burrows, with evidence of sparse *Thalassinoides* spp. burrows limited to the interbedded horizontal clayey fine sands. This appears consistent with multiple storm-generated depositional events being separated by periods of quiescent deposition during which burrowing would have been favored.

In further support of a high-stress depositional environment for the Cypresshead Formation is the low diversity macrobenthic infaunal trace fossil assemblage outlined in this paper. Characteristic of shallow-water facies with relatively coarse substrates, this assemblage possesses relatively low diversity in comparison to the modern shelf off south-central Texas (Hill, 1985), but is similar to that described by Kussel and Jones (1986) for the late Pleistocene to Holocene Satilla Formation deposited seaward of the Cypresshead in southeastern Georgia and northernmost

Florida. Although *Ophiomorpha* spp. and *Skolithos* spp. traces are dense within select beds correlated to nondepositional discontinuities, the overall density of traces appears to decrease significantly with increased water depth. This is inconsistent with the opinion of Howard and Reineck (1972) that under ideal conditions bioturbation should increase with increasing water depth, due to fewer bottom disturbances such as storms. Possible causes for this trend might include deeper water wave base impacts of storms or nutrient conditions unsuitable for supporting a more dense and/or diverse assemblage.

The reader is referred to Fountain (2009) for a more detailed review of the Cypresshead Formation in both north-central Florida and southeastern Georgia, including information pertaining to the regional correlation, depositional timing, mineralogy, and provenance of the unit.

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## **AN INTERPRETATION OF NEAR SURFACE JOINTING NORTHERN POLK COUNTY, FLORIDA**

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Joints and small-displacement normal faults are commonly found in exposures of Plio-Pleistocene sediments at sand mines and borrow pits in Northern Polk County, Florida. They are preserved in materials of the Cypresshead Formation and some reworked Cypresshead materials (mapped by Campbell, 1992), that were sufficiently indurated during their geologic history to be subject to brittle deformation. Although the formation of karst and paleokarst in Northern Polk County has resulted vertical displacements large enough to account for the observed brittle features, the relatively wide geographic distribution and relatively consistent orientations of the features suggest the presence of a relatively singular regional structural fabric. That fabric is characterized by extension to the northwest and southeast along an axis with an orientation of about North 60° East.

Figure 1 shows the locations of outcrop in Northern Polk County where measurements of brittle structural features have been made. The observed features consist of nearly vertical sets of extension joints. In some cases where displacement of bedding and/or joints is apparent, the features are more appropriately referred to as small-scale, high-angle, normal faults. In some places the joints occur as open fractures. More typically the joint openings are filled by silt and clay-sized particles.

Figures 2 and 3 are photos of prominent joint sets in an exposure of well-indurated clayey sand located on Deen Still Road. Note the odd structures apparent in Figure 3. Their significance is not clear.

Figures 4 and 5 are photos of joint sets and small-scale faults at Pit-17. Note how differential erosion of outcrop faces accentuates the joints, which are filled by materials that are more fine-grained than the rock that they cross-cut. Field observations, that are not apparent in the photos, indicate that at least some of the joints are cross-cut by burrows of presumed marine origin. Apparently the sediments at the site were deposited, subjected to subaerial weathering, which produced induration sufficient to make the sediments subject to brittle deformation, and then transgressed again subjecting the area to submarine burrowing.

Figure 6 is a photo of very-closely-spaced joints at Pit-7, that appear almost to constitute a foliation. Figure 7 is a closer view of the same outcrop in which bedding planes are more apparent. Figure 8 is a detail, from the same outcrop, of a fulgurite that appears to cross-cut the fabric. Figure 9 and 10 are photos of an en-echelon set of high-angle normal faults at Pit-7, with displacements ranging from about 1 to 3 feet. Note that the faults cross-cut a prominent subaerial weathering horizon. Another prominent weathering horizon, located about 30 feet higher in the section, appears to have been formed after faulting, by a shallower water table.

The observed brittle deformation could occur as some areas are warped by greater rates of uplift (or subsidence) than adjacent areas. Tectonic uplift of the coastal plain of Georgia and Florida

was recognized by workers including Hoyt (1969) and Winkler and Howard (1977). Workers including Opdyke et al. (1984) recognized isostatic rebound as a mechanism for uplift. Great masses of carbonate rock are unloaded from the Florida Platform by chemical dissolution as karst landscapes develop. Buoyant forces cause the crust to rise until a new equilibrium is reached between weight and buoyance. Rates of dissolution are greater in some areas (and times) than others. Accordingly, rates of uplift are not constant. Adams et al. (2010) recently modeled the evolution of landscapes due to interactions of karst formation, uplift, and other factors.

Stresses in the outermost layers of a concentrically warped (folded) sequence of rocks are tensional; the rocks are stretched, as illustrated schematically by Layer A in Figure 11. Tension is relieved by extensional features, like joints and normal faults, that accommodate the addition of volume as voids form when the rock layers are pulled apart. Strike orientations of individual joints, or faults, are notoriously random. However, sets of many features that are related to the same stress are likely to form along preferred orientations.

A total 51 measurements of joint and fault attitudes, from 6 mines, were analyzed statistically. Figure 11 is a contour of 4 percent area of poles of the attitude measurements plotted on a Lambert Net. The well-defined clusters of data points suggest 3 consistent regional joint orientations that are common to all of the sites where measurements were made. Orientations of the 3 joint sets are superimposed upon the contoured pole data in Figure 12.

The field measurements of joint and small-displacement faults found in the Plio-Pleistocene deposits of Northern Polk County are consistent with a singular regional structural fabric that is characterized by extension to the northwest and southeast along an axis with an orientation of about North 60° East.

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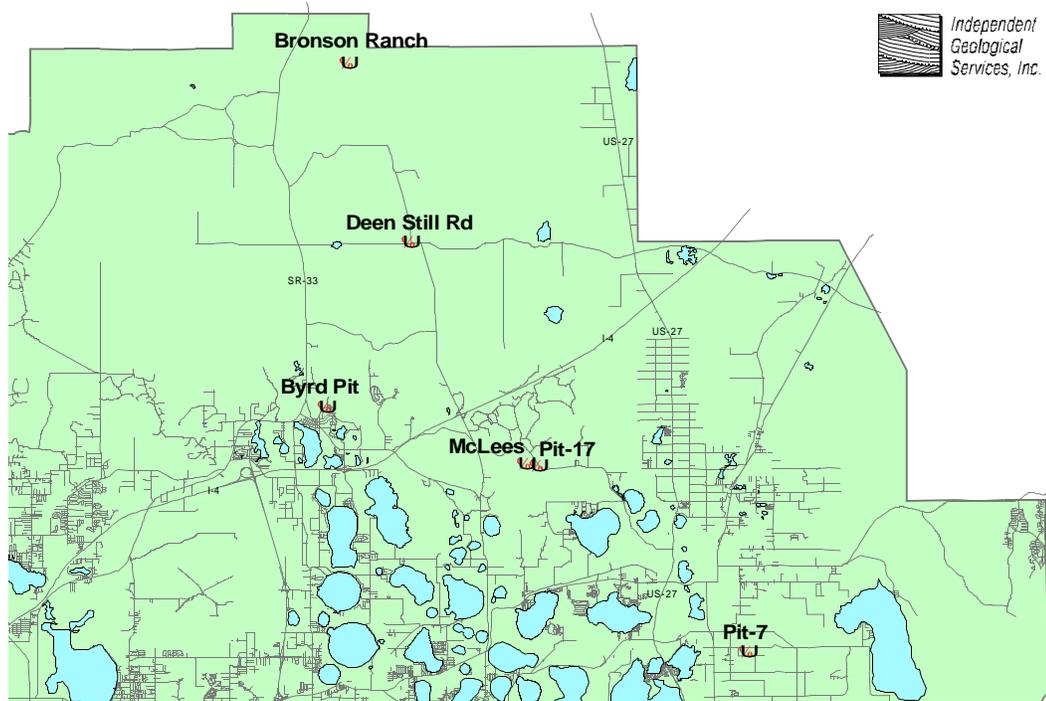


Figure 1. Outcrop Locations



Figure 2. Joints in Outcrop on Deen Still Road (Facing North)



Figure 3. Joints and Odd Structures in Outcrop on Deen Still Road (Looking Down)



Figure 4. Joints at Pit-17 (Facing Northwest)



Figure 5. Joints and Normal Faults at Pit-17 (Facing Northeast)



Figure 6. Closely-Spaced Joints (Foliation?) at Pit-7 (Facing North)



Figure 7. Closer View of Bedding and Joints at Pit-7 (Facing North)

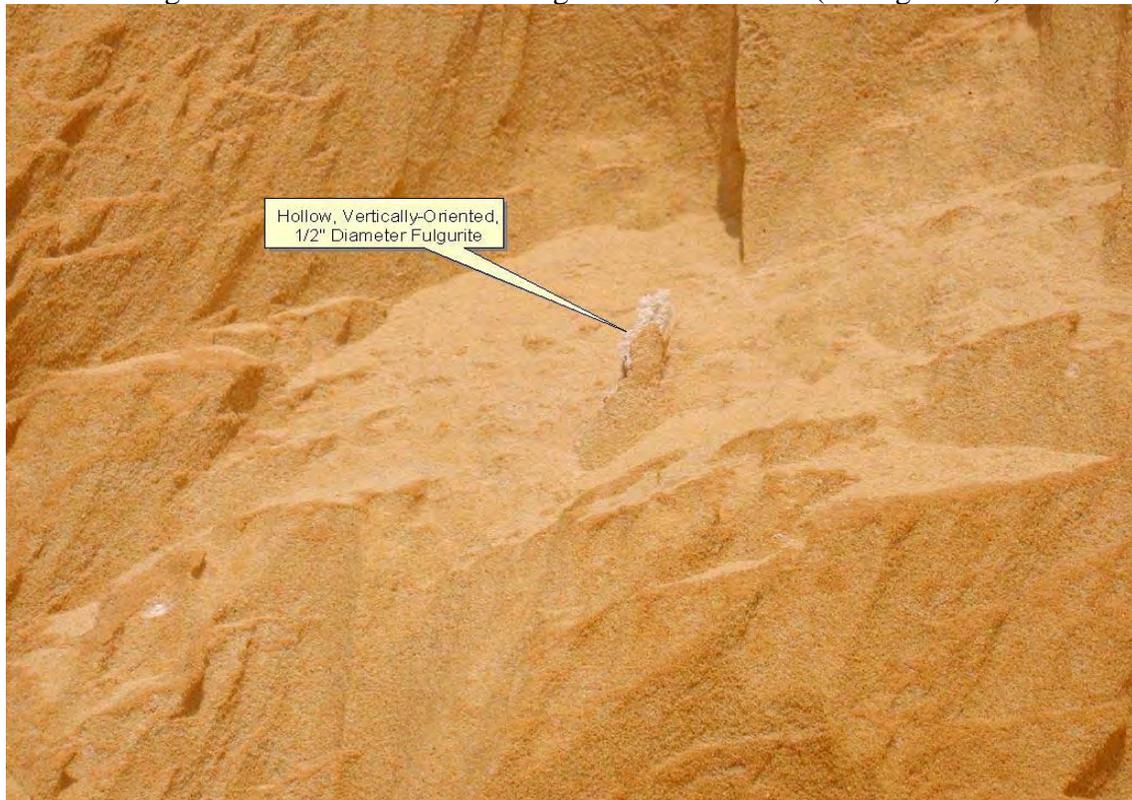


Figure 8. Fulgurite Cross-Cutting Joints at Pit-7 (Facing North)



**Figure 9. A Series of En-Echelon, High-Angle, Normal Faults at Pit-7**



**Figure 10. Closer View of En-Echelon, High-Angle, Normal Faults at Pit-7**

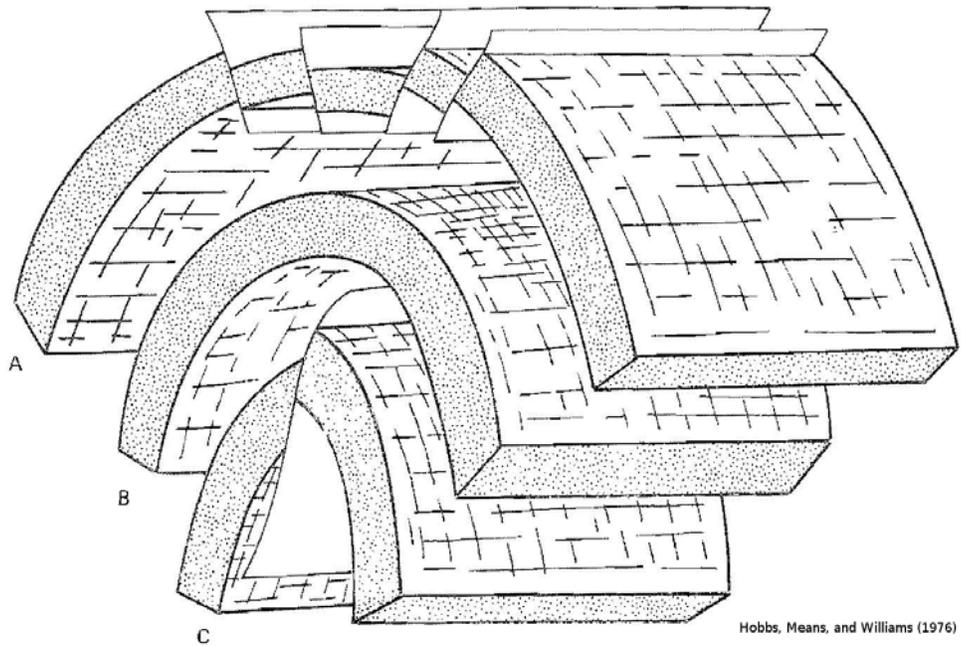


Figure 11. Block Diagram of a Concentrically folded sequence of rocks

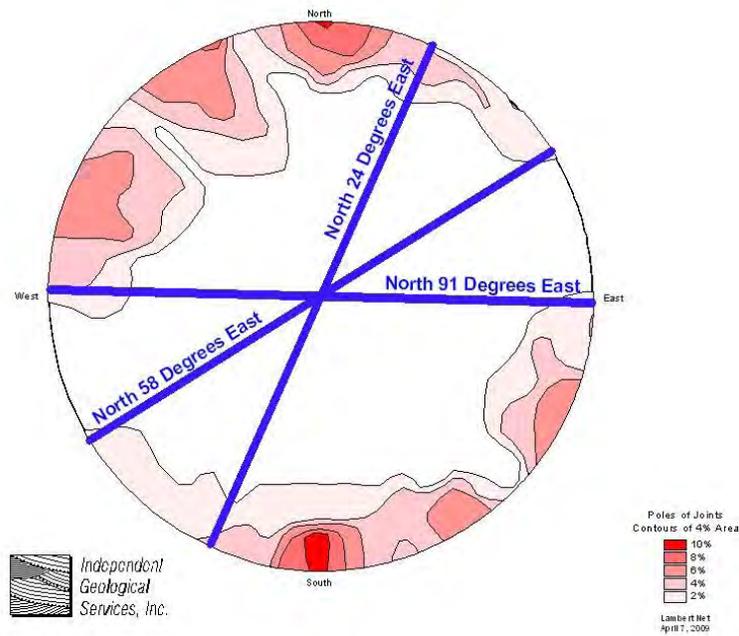


Figure 12. Preferred Orientations of Joints and Faults in Northern Polk County

## **A PLAUSIBLE EXPLANATION FOR RAISED COASTAL RIDGES AND TERRACES ALONG THE AXIS OF PENINSULAR FLORIDA**

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### **Introduction**

Evidence from topographic surveys, paleontological analyses of drill cores, and sea level history has presented a conundrum vexing geologists in Florida for the better part of the last century. Stated simply: why do young, marine ridges and terraces of north-central Florida occupy such high elevations? In this field guide contribution, the topographic and fossil data of the terraces are presented along with the recent sea level history to set up the geologic problem. Then, a hypothesis is presented to resolve the seemingly conflicting evidence. Lastly, the hypothesis is tested for plausibility with a simple numerical model.

### **Topographic Evidence**

The conspicuous ridges and terraces that trend shore-parallel from South Carolina through peninsular Florida have inspired numerous studies (Figure 1). Early 20<sup>th</sup> century geologists called on Pleistocene Atlantic transgressions to explain these features. Cooke (1936; 1943) and Parker and Cooke (1944) correlated the ridges and terraces across multiple states on the basis of correspondence of elevations. Winker and Howard (1977) attempted to correlate these relict shorelines along the southeastern Atlantic coastal plain independent of the assumption of “absolute tectonic stability” since the Pleistocene. Based on qualitative geomorphological characteristics, they identified three shorelines as the Chatham Sequence (~5-15 m amsl), the Effingham Sequence (~20-40 m amsl), and the Trail Ridge Sequence (~35-100 m amsl) and speculated that these shore parallel surfaces had been “tectonically warped”. However, no evidence for true tectonic activity exists for the region during the time since these features might have been constructed. The first piece in the landscape evolution puzzle of north Florida is the topographic evidence; Trail Ridge occupies an elevation of approximately 70 meters above sea level in western Clay County, FL.

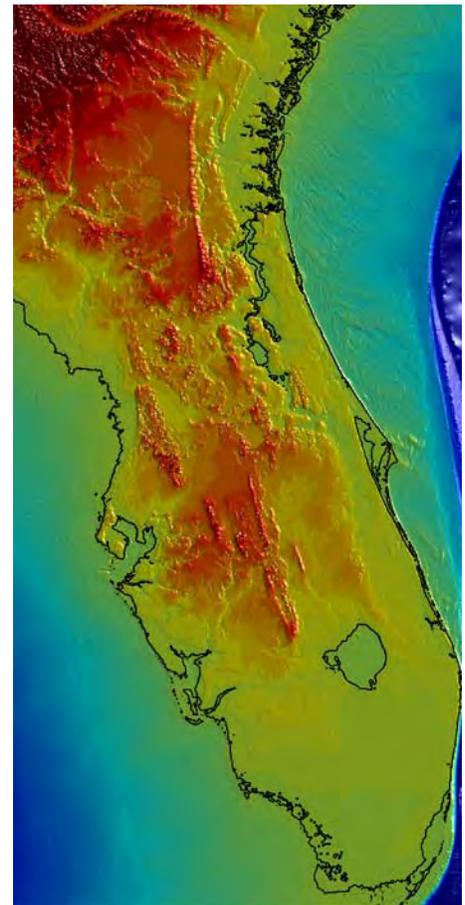


Figure 1. Hillshaded view of digital elevation model showing ridges and terraces of the Florida peninsula.

### **Paleontological and Mineralogical Evidence**

Further evidence is contained in the sedimentary deposits of the Florida portion of the Trail

Ridge landform (Figure 2). In 1977, drilling operations on Trail Ridge in southern Georgia revealed that the ridge deposits, consisting of host sediment of size medium to fine sand, contained marine fossils that included, among other things, bivalve mollusks, gastropods, and bryozoans (Pirkle and Czel, 1983). This fossil assemblage was interpreted to represent a depositional environment of shallow water with temperatures similar to those of modern North Florida analogue environments. In addition, all of the fossils were considered extant, indicating an age of deposition younger than late Pliocene or Pleistocene. Heavy mineral ore bodies contained in Trail Ridge deposits are consistent with an interpretation of a beach ridge depositional environment. Pirkle and Pirkle (1984) maintain that fine sands were winnowed away at this setting, leaving behind enriched heavy mineral deposits. It is thought that subsequent iron leaching by groundwater through ilmenite sands resulted in titanium enrichment (Carver et al., 1986). Trail Ridge is a very well known source of economically viable Titanium and mining companies have taken advantage of these enrichments since the early 1900's. The sedimentary evidence points to an interpretation of shallow marine depositional setting for Trail Ridge. This is the second piece in the landscape evolution puzzle of north Florida.

### Sea Level History

The conundrum arises when the sea level curve is considered. Figure 3 shows a smoothed, interpolated plot of Miller et al.'s (2005) sea level compilation for the time since the early Pleistocene. Inspection of the timeline shows that there have indeed been intervals during which sea level was higher than present day (e.g. MIS 5e ~125ka, MIS 11 ~400ka), but at no time has it been sufficiently high to deposit marine fossils at elevations

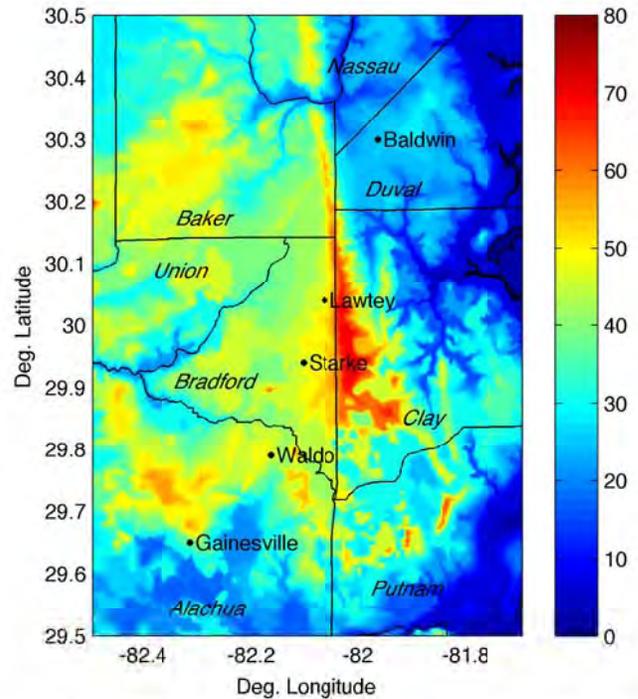


Figure 2. County map of north central Florida overlain on 3-arc second digital elevation model of the same region. Elevations in colorbar are meters above modern sea level. County names shown in italics. Cities shown as black dots.

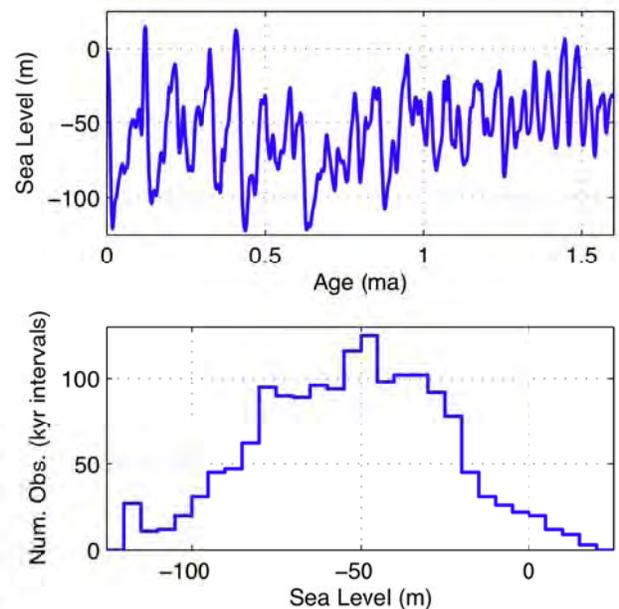


Figure 3. Miller et al. (2005) sea level history since early Pleistocene, interpolated and smoothed.

occupied by Trail Ridge today (~35-100 m amsl). The frequency distribution of sea level occupation levels, shown in the lower panel of Figure 2, reveals that sea level has only been above modern elevation for a brief fraction of the total time since the Pliocene. After considering the topographic evidence, sedimentary evidence, and sea level history, the conundrum can be clearly stated: *How can a Pleistocene depositional feature of nearshore marine origin exist at some 70 meters elevation in a tectonically quiescent setting, when the Pleistocene sea level record shows no evidence of such a highstand?*

### Hypothesis: Karst-Driven Isostasy

An answer to this riddle was proposed by Neil Opdyke and his colleagues at the University of Florida in the early 1980's (Opdyke et al., 1984). Several studies have been conducted to examine spring water carbonate chemistry in Florida (e.g. Willett, 2005). After inspecting dissolved carbonate chemistry concentrations of natural spring waters, the researchers hypothesized that voidspace creation through karstification of the Florida carbonate platform, might provide sufficient crustal mass loss to drive isostatic rebound. This uplift mechanism could account for the modern elevation of the raised Pleistocene ridges much in the same way that unloading of continental ice sheets has driven uplift in northern North America and Scandinavia. The main difference in the Florida platform case, however, is that mass loss is conducted by the growth of subsurface void space within the uppermost crust.

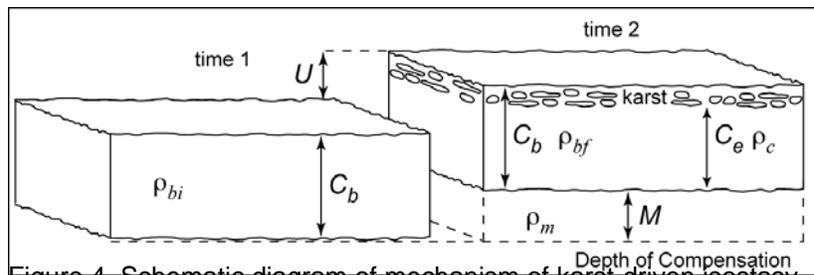


Figure 4. Schematic diagram of mechanism of karst-driven isostasy (from Adams et al., 2010).

### Model Testing of Hypothesis

Opdyke et al. (1984) conducted an example calculation to show that the elevation of Trail Ridge roughly corresponds to the expected elevation if isostatic rebound was the responsible uplift mechanism, given the current rates of dissolution. This verification was conducted more formally by Adams et al. (2010) through a numerical model that combines an assumed paleoprecipitation history, a linear karstification function, and sea level oscillation-driven platform exposure to calculate a history of isostatic uplift since the early Pleistocene. Figure 4 shows the schematic representation of the hypothesis being tested with the numerical model. Output from the model includes highstand position (elevation) markers in the landscape that are initially emplaced at the elevation occupied by each highstand, and subsequently raised according to isostatic uplift history. Any highstand marker that is transgressed is numerically erased from the geomorphic record – a concept referred to (in glacial moraine geomorphology) as “obliterative overlap”. The end result of a model simulation is a series of highstand markers with ages and elevations that have an opportunity for preservation, given the combined effects of uplift and sea level histories. Figure 5 shows the results of a numerical simulation overlain on a series of cross-platform (west to east) topographic profiles of the north central Florida region. Details of the

numerical simulations are discussed in Adams et al. (2010). The net result is that plausible ages corresponding to the, Trail Ridge, Effingham, and Chatham sequences, respectively, are 1.44 Ma, 408 ka, and 120 ka.

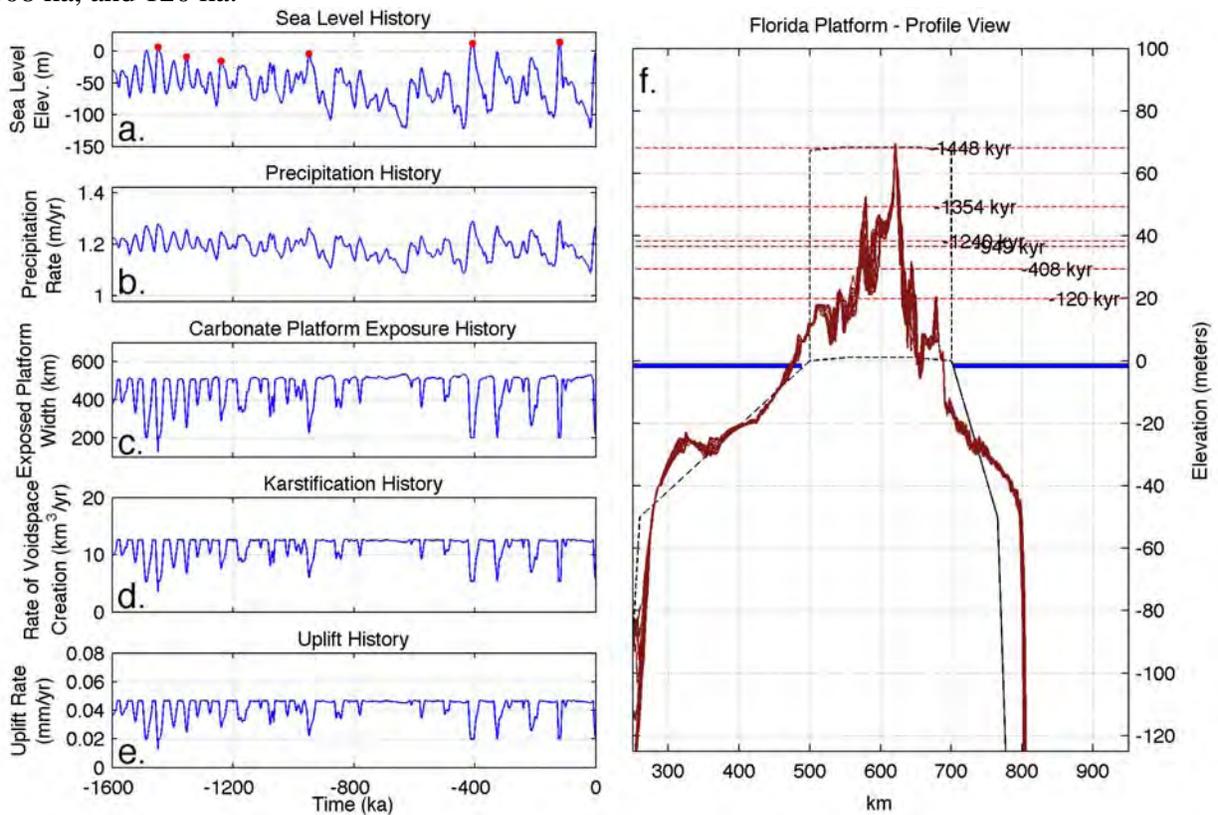


Figure 5. Results of numerical simulation for karst-driven uplift and ridge/terrace preservation in north-central Florida (from Adams et al., 2010).

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**VMC – FLORIDA ROCK DIVISION  
SANDLAND PLANT  
LAKE WALES, FLORIDA**

C.T. Williams, P.G.  
*Vulcan Materials Corporation*

**Introduction**

Prospect auger drilling for the Sandland Plant mining operation began in 1978 on property located east of Lake Wales, Florida. The site was identified based upon sand mining that had been conducted on the property during the 1960's. Florida Rock leased 420 acres from Mammoth Groves, Inc. in 1979 and built a plant and hydraulic suction dredge. Mining and production began in early 1980 with concrete sand as its sole product and has been in continuous operation since the inception date. Masonry sands, golf course specialty products, sands for the manufacture of roof tile and structural fill sands were later products that were produced and sold by the operation. The mine site property was eventually purchased from the Lessor in 1994 thereby enabling Florida Rock to have full control over the industrial minerals deposit. Additional mineral reserve lands to the northwest were added to the operation in 2000 following reverse-air circulation drilling of 120 acres adjoining the existing zoned and permitted mining operation. The mining operation is currently in the process of phasing down toward the ultimate cessation of all mining operations at this site with the northern reserves tract the last area mined. Reclamation has been performed over the years concurrent with the mining operation and is currently ongoing in accordance with local and state regulatory requirements. See Figure 1. (USGS topographic map, Lake Wales Quad, date 1952, photo-revised in 1972 & 1990)

**Mining of Northern Reserves**

Mining of the northern reserves began in the early 1990's while dredging and processing continued on the southern reserve body. Following many years of dredging the northern sand reserve body, the pit was used as a below-grade tailings impoundment for process sands and silt waste from the plant. Figure 2 shows an aerial photograph, dated February 2000, of the North Reserve Area and depicts the initial placement of tailings. Also noted on the map is the area designated as "Area Purchased Later." This area represents additional sand reserves that were acquired in 2000. This area is on the eastern slope of the Florida Lake Wales Ridge Physiographic Region and is part of the Pliocene/Pleistocene Dunes Complex. The topographic lower flats to the east of the Lake Wales Ridge slope are Pleistocene Undifferentiated sediments (Figure 1 can be reviewed for elevation reference). Cessation of mining in the Northern Reserve Area occurred in late 2007. Figure 3, (aerial photography dated: January 2009) shows the progression of tailings placement in the southwest portion of the depleted pit. An area on the north end of the depleted reserves, which comprises approximately 7 acres, has been identified for dedication to Polk County as a recreation park for the adjacent residential community (area marked in green).

## **State, County and Federal Regulatory Authorities**

Reclamation of Industrial Minerals mines in the state of Florida was mandated with passage of the “Florida Mining and Reclamation Act” and as currently implemented by Chapter 62C-39 Florida Administrative Code. The Florida Department of Environmental Protection (DEP), Bureau of Mining and Minerals Regulation (BMMR) is charged with oversight responsibility of mining operations to ensure compliance with the mine reclamation requirements. Pursuant to these requirements, all mine operators were required to submit drawings of their respective property holdings and indicate thereon what lands had been disturbed by mining and mining related activities prior to January 1, 1989 and what lands they planned to mine subsequent to that date. Those lands disturbed by mining and mining related activities prior to January 1, 1989 are considered to be “non-mandatory” and are not subject to state reclamation requirements. Conversely, those lands disturbed by mining and mining related activities after January 1, 1989 are considered to be “mandatory” and must be reclaimed to minimum state reclamation standards.

Unlike the reclamation requirements imposed upon limestone mines, sand mines were not required to submit detailed plans depicting reclamation designs. Instead, a performance standard was established which was required to be met at the time of mine closure and release from reclamation requirements by the state of Florida. Such reclamation was also to be consistent with the intended post-mining land use, i.e. pine plantation, pasture, etc. At the time, these requirements were minimal compared to present day standards and represented the minimum standard where there was not a more stringent local ordinance or zoning requirement related to mine reclamation. Later permitting requirements, chiefly associated with Management and Storage of Surface Waters (MSSW) permits and subsequently Environmental Resource Permits (ERPs), would dictate the submittal of detailed drawings depicting slopping of all bank-cuts to specified depths below water, grading and contouring of disturbed uplands, and revegetation of both shorelines and upland areas.

Local regulations are administrated by Polk County, Board of County Commissioners, Community Services Department – Development Services Division. The Sandland Sand Plant is required to obtain a Conditional Use Permit (CUP) in compliance with all relevant requirements of the Polk County Land Development Code. Many of the CUP requirements under the rules are similar to other state and Federal rules and regulations, but the County can and does impose additional “conditional requirements” and if any conditions of approval conflict with this CUP or the Polk County Land Development Code, the more stringent requirement shall apply.

## **North Reserve Pit Reclamation Plan**

Compliance obligations with state and local reclamation requirements and conditions by the Sandland operations initially would be accomplished by meeting the minimum bank-cut sloping standards of 50-foot property line setback, 4-to-1 horizontal-to-vertical slop grading to mean water elevation and sloping below water of 5H:1V to a depth of six-feet below mean water level. Placement of tailings into the southern end of the Northern Reserve Area following the addition of the new reserve parcel offered operation management the option to maximize the extraction of reserves along the western property boundary, then use placement of tailings along the western

pit for reconstruction of the sloping requirements. The approved detailed reclamation drawing submitted to the BMMR for modification to the permit filed in early 2009 can be seen in Figure 4. Reclamation Cross Sectional Plan drawings of the approved modification plan can be viewed in Figure 5. Fine Aggregate production by the operation is being done in the Southern Reserve Pit. Process waste from this production process is pumped to the Northern Reserve Area for the reconstruction of the reclamation requirements, see Figure 6 for reference. Photographs of the western bank-cut and the beginnings of the tailings placement for reclamation can be seen in Figures 7 thru 9.

VMC – Florida Rock Division management is presently giving consideration to future land use concepts for the post mining and reclamation processes for the land holdings of Sandland Sand Plant. Figure 10 shows a Concept Drawing of one option for the Northern Reserve Area. Developments of lakes by mining operations create an excellent fresh water lake suited for fishing, recreation and residential development.

## VMC Sandland Sand Mine *Lake Wales, FL*

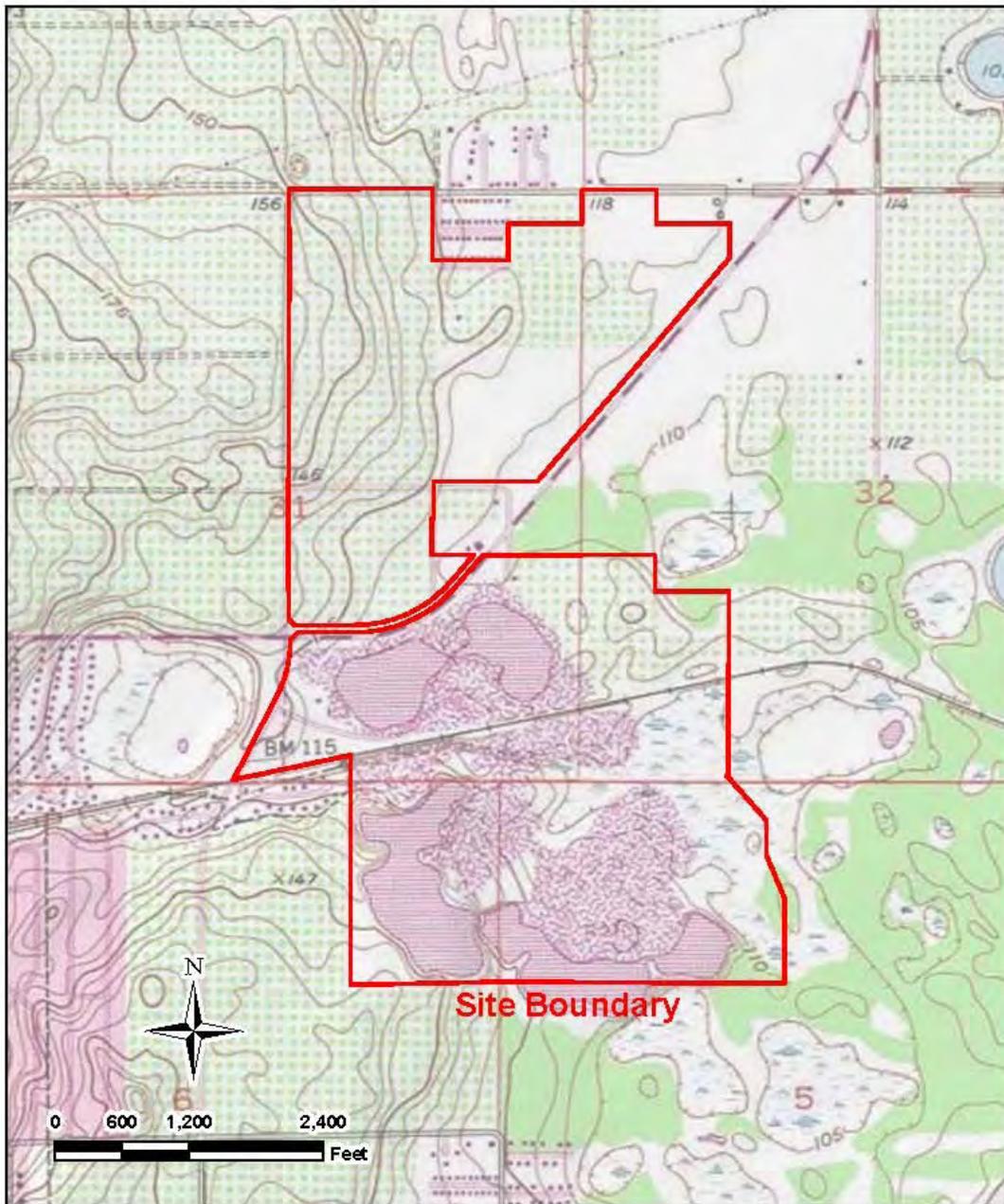


Figure 1: Topographic map of FLD – Sandland Sand Plant located east of Lake Wales, Polk County, Florida. Map base: USGS Lake Wales Quadrangle 7.5 Minute Series, Photo-revised 1972. Topographic relief to the west is the eastern slope of the Lake Wales Physiographic Region.

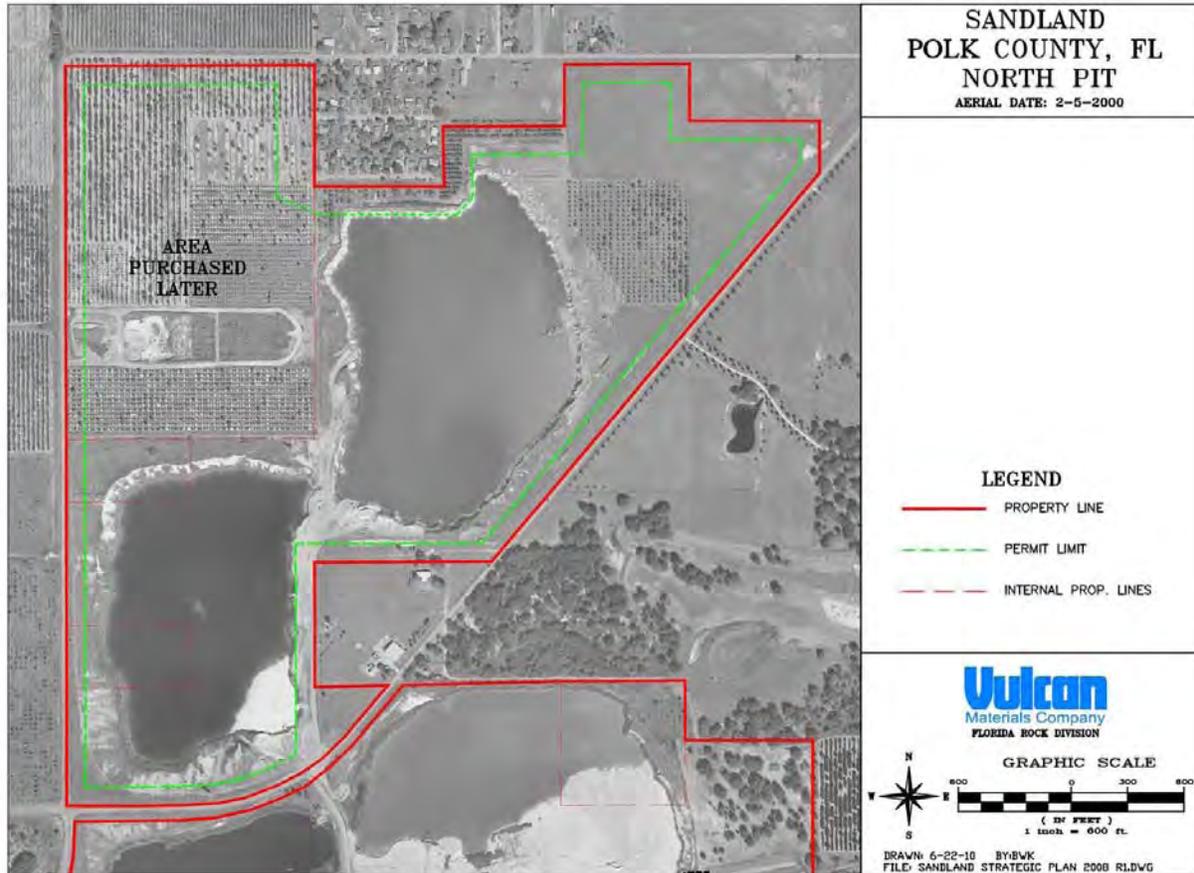


Figure 2: Aerial photography of the Northern Reserve Area; date: February 2000. Initial placement of tailings can be noted in the southern end of the depleted pit. Acquisition of additional reserve acreage is noted to the northwest.

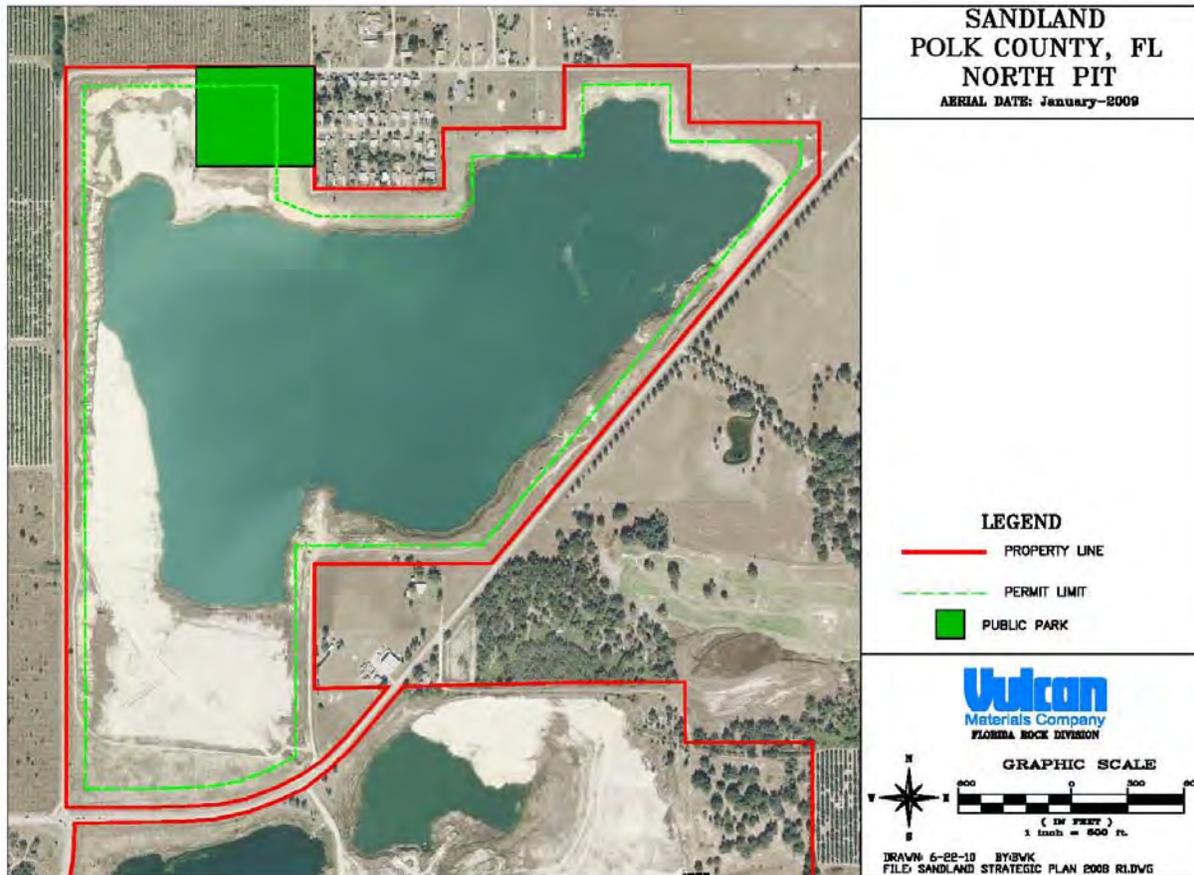


Figure 3: Aerial photography of the Northern Reserve Area; date: January 2009. Progression of tailings placement for reclamation can be noted on the western side of the Northern Reserve Area. The area highlighted in green denotes a 7 acre portion of the property that has been identified for dedication to Polk County as a recreation park for the adjacent residential community.

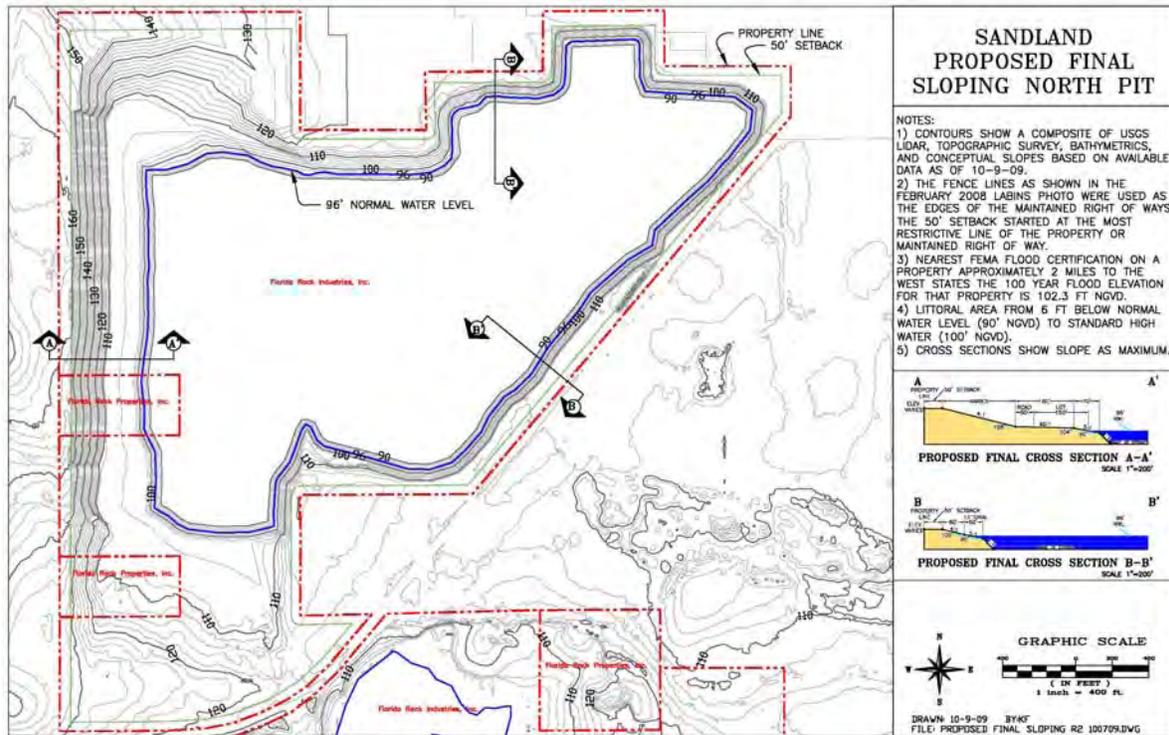


Figure 4: Detailed reclamation drawing of the Northern Reserve Area depicting sloping of all bank-cuts to specified depths below water, grading and contouring of shorelines and upland areas including the western area of the tract reconstructed by tailings placement. See Figure 5 for detail drawing of Cross Section details of shorelines and upland areas.

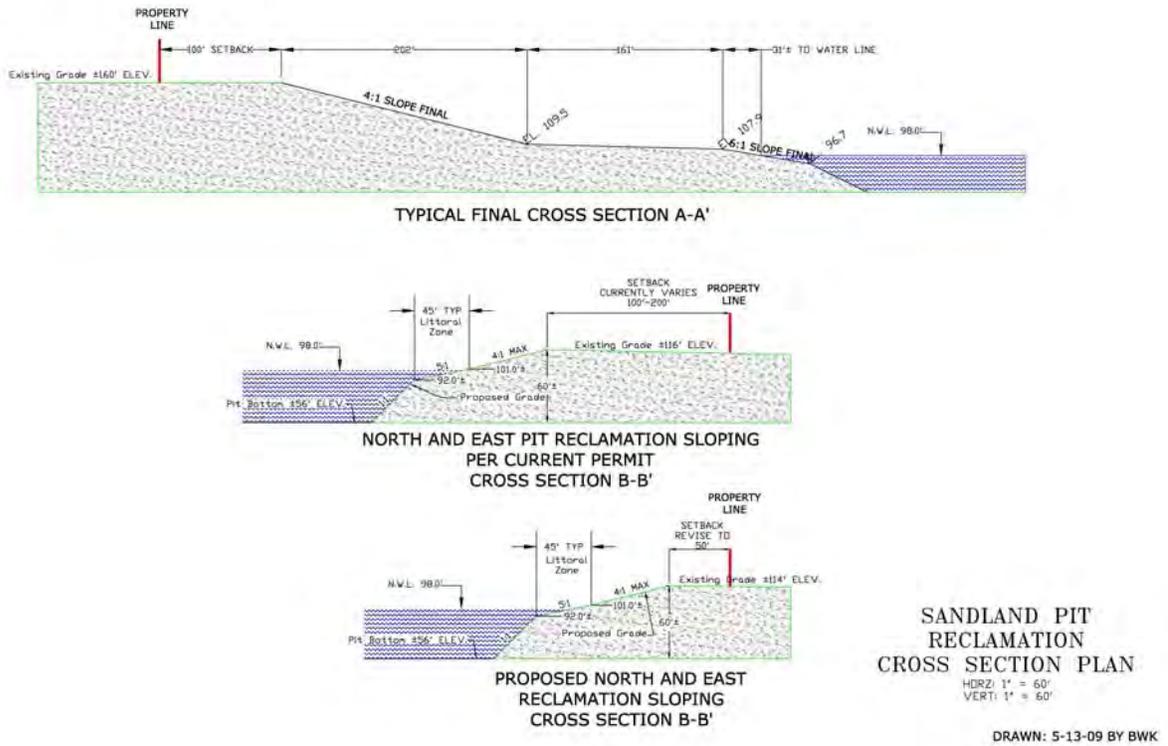


Figure 5: Detailed drawing depicting sloping of bank-cuts to specified depths below water, grading and contouring of shorelines and upland area reconstructed by tailings placement along the western boundary of the depleted pit. See Figure 4 for location of sections.

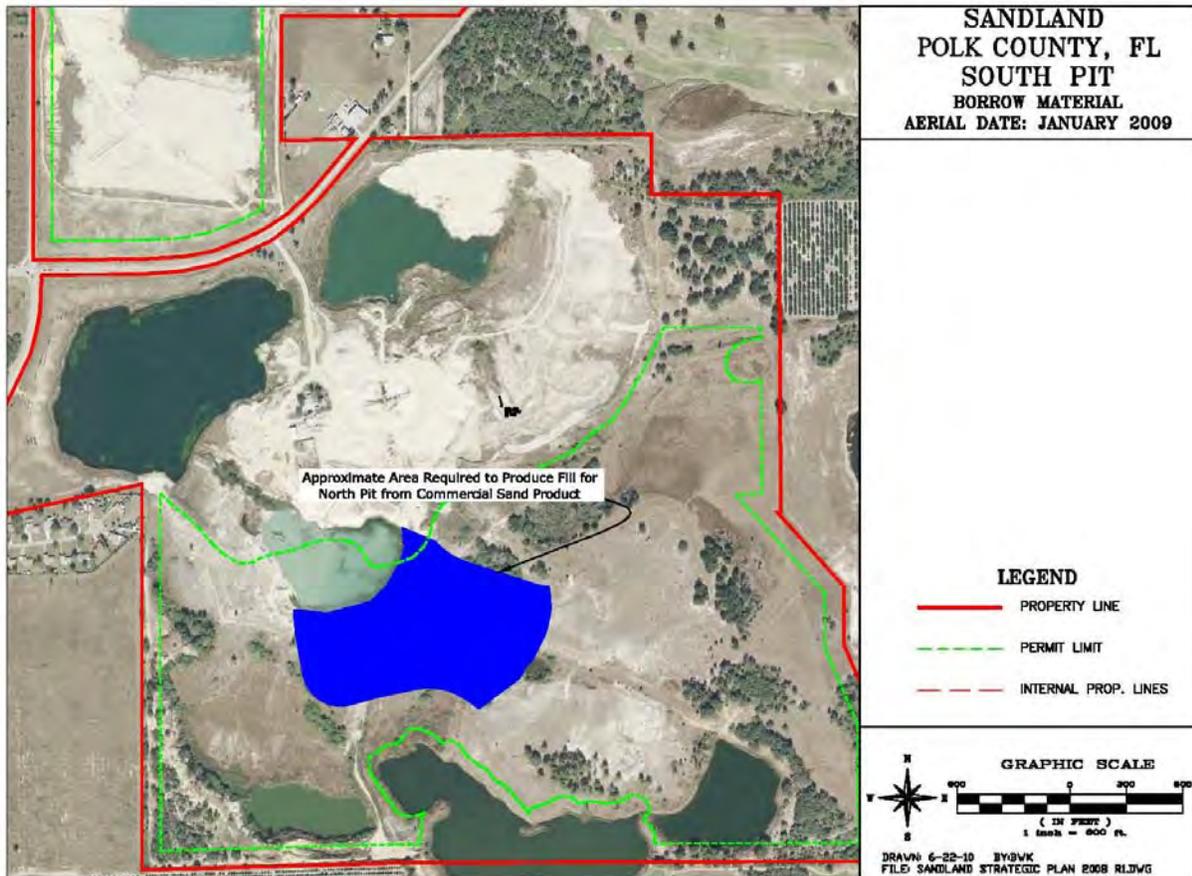


Figure 6: Aerial photograph on the Southern Reserve Area. Area highlighted in blue is the source area for the continued production of Fine Aggregate products and process tailings to be used for the reconstruction of the western upland area of the Northern Reserves Pit. Date of aerial photography January 2009.



Figure 7: Photograph looking northwest towards the western post mining bank-cut. Placement of reconstruction tailings can be noted on the left side of the figure. Post-mining reconstruction is from south-to-north. This bank-cut will be sloped, graded and vegetated in accordance with approved reclamation plans.



Figure 8: Photograph looking north along the edge of the western post-mining bank-cut. Placement of reconstruction tailings can be noted in the foreground.



Figure 9: Western post-mining bank-cut depicting bedding of the Pliocene/Pleistocene Formation mined for the production of FDOT Fine Aggregate products by the Sandland Sand Plant. The bank will be graded to the required slope in accordance with the approved Post-Mining Reclamation Plan. Eolian sand can be noted atop the more consolidated Formation and cascading down the post-mining bank-cut.

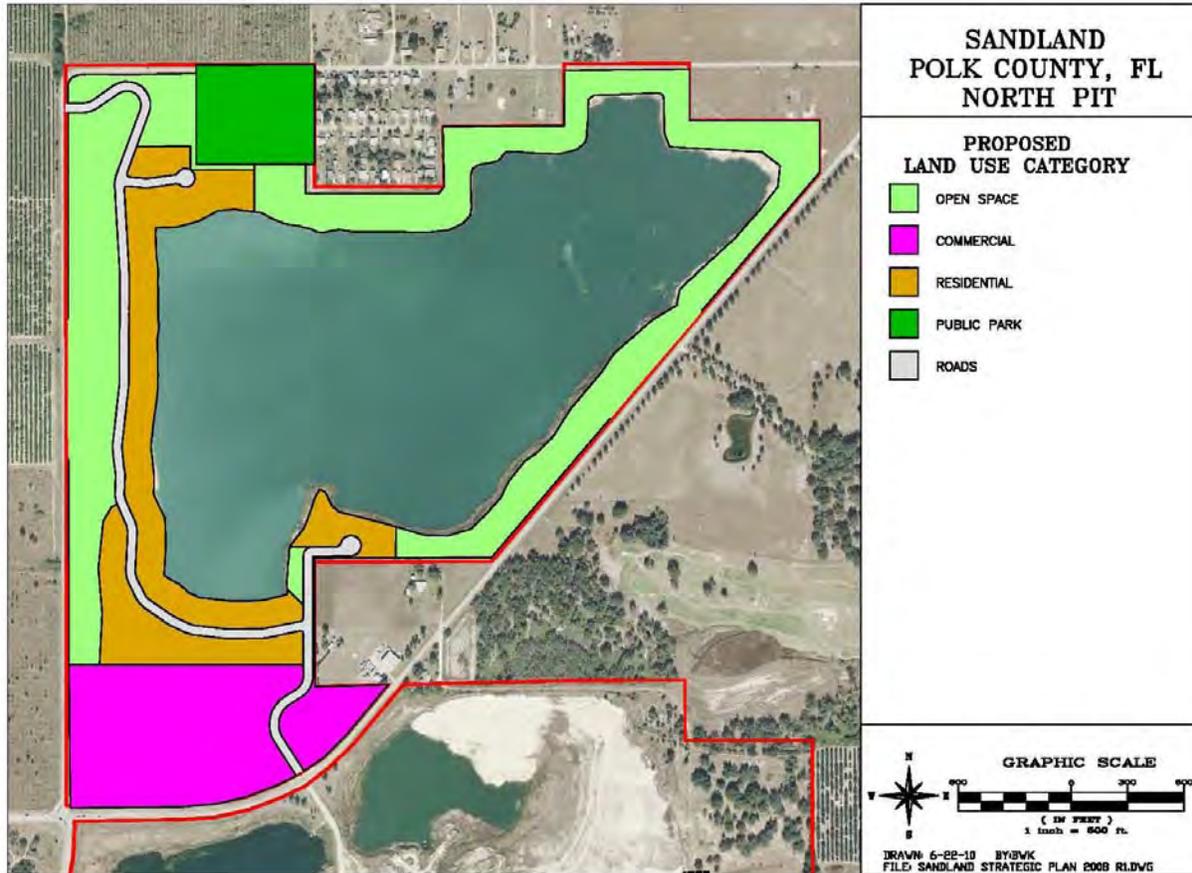


Figure 10: Concept Drawing of intended “post-mining” land use for the Northern Reserve Pit. Description of color coding: light green - Open Space; lavender – Commercial; orange – Residential; dark-green – Public Park; light-gray - Roadways.

## **COMMERCIAL SAND PRODUCTION AT THE CEMEX DAVENPORT SAND MINE, POLK COUNTY, FLORIDA**

Matt Lewis, P.G.  
*CEMEX*

### **Background**

The Davenport Sand Mine has been in production for over 50 years. CEMEX currently operates a hydraulic dredging style sand mine and fractionating sand plant on site. In addition, CEMEX operates a nearby ready-mix concrete batching plant and concrete block plant.

### **Geologic Setting**

The Davenport Sand Mine is located in northeastern Polk County on the Central Florida peninsula (Figure 1); it is situated along the eastern flank of the Lake Wales Ridge physiographic province. The Geologic Map of Florida (Scott et al, 2001) indicates re-worked Cypresshead Formation (Huddleston, 1988) as the near-surface geologic unit present on the site. Descriptions from the geologic logs of sand prospecting borings conducted on site are consistent with those given for reworked Cypresshead. Fine-grained sands near the surface grade into medium-coarse grained sand at depths typically greater than 15 feet bgs. Medium-coarse sands then grade into a finer kaolinitic silty-sand, typically below 50 feet bgs. The unconsolidated sediments near the surface on site form the upper part of a shallow un-confined surficial aquifer. Groundwater present in this surficial aquifer leads to ponds forming where excavations are dug below the water table.

### **Process Description**

A barge mounted suction dredge (Figure 2) floats in a groundwater-filled excavated pit. Anchor ropes are attached from the dredge to heavy blocks positioned around the edges of the pond. Winches attached to these anchor ropes are used to move the dredge laterally while a pivoting ladder is used to raise & lower the depth of suction. The pond is excavated to the depth and acreage prescribed in the mine plan and according to permit conditions. Sand is pumped as a slurry from the dredge through high-density polyethylene (HDPE) pipes to a feed preparation station where coarse debris is screened out in a trommel. The slurry is then fed to the top of the sand plant (Figure 3) through a series of cyclones, hydrosizers, and shaker-screens; the sand is then sorted and fed into one of four large bins based on grain-size (see figure 4 for a plant flow diagram). Depending on the product being made, sand from the four bins is then blended in a controlled way to achieve the desired product specification; this is known as a fractionating or “recipe” style sand plant. Sand which is finer than the finest size used (typically minus #100 mesh) as well as any silts or clays introduced to the plant are flumed out of the plant to a settling pond. The plant has an additional “caustic scrubber” circuit which utilizes attrition scrubbers and sodium hydroxide solution to clean sand which is heavily colored with organic staining. The caustic circuit can be activated or de-activated as needed depending on the degree of staining in the feed sand and the specifications of products being made at any given time.

## **Products and Uses**

Various sand products are formulated and then either used internally (at Cemex ready mix plants for example) or sold to external customers; products include: Commercial Concrete Sand, Golf Course Blends (37M, Trap Sand, Top Dressing, Greensmix, Divot Sand), Mason Sand, Asphalt Sand, Beach Sand, and Underdrain Sand. Sand produced by the Davenport Sand Mine is hauled off site by either truck or rail car. Some of the sand produced on-site is further processed just off-site for applications such as filter sand (by the Standard Sand & Silica Company) and potting soil (by Florida Potting Soils, Inc.)

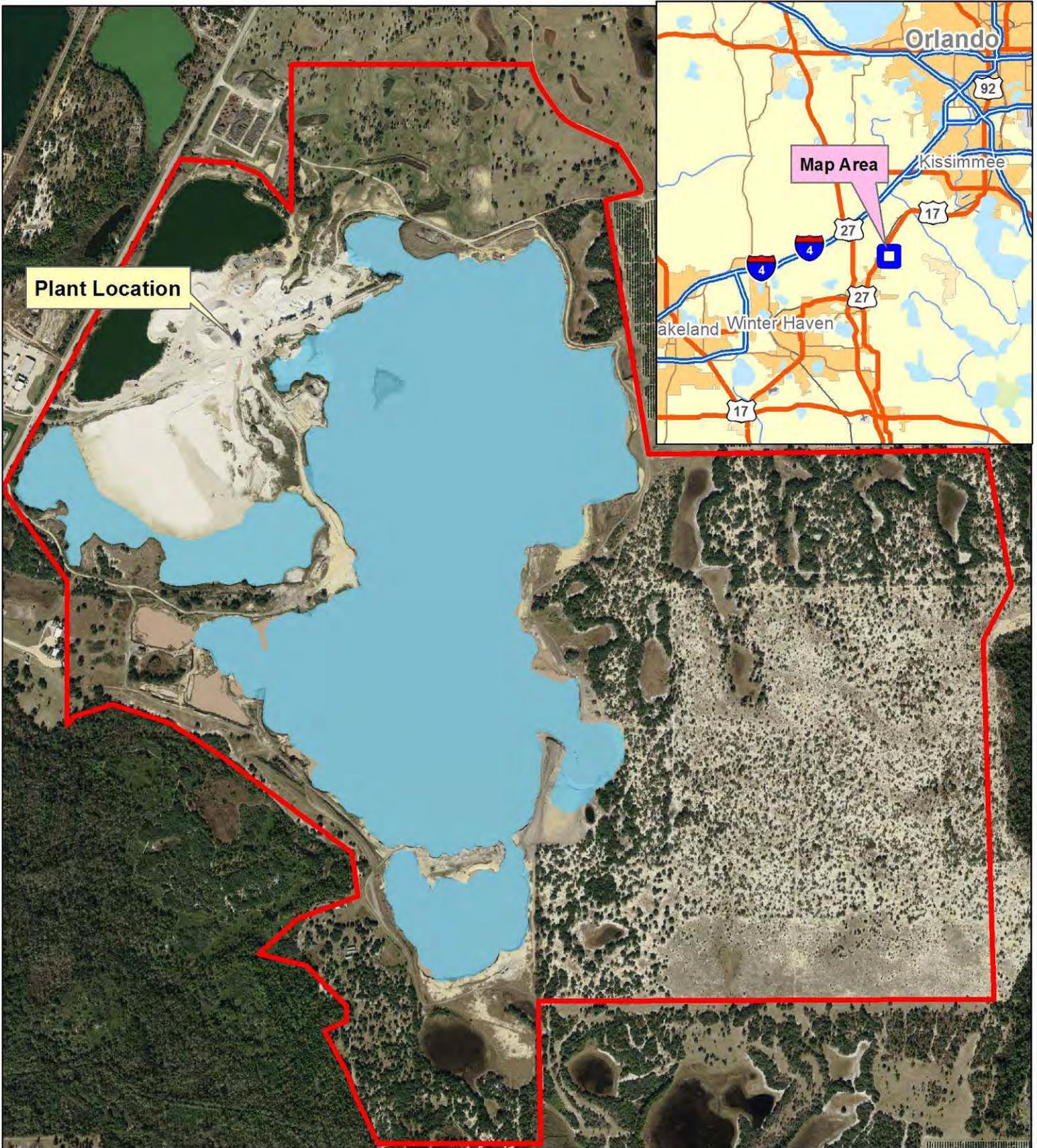
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Figure 1

# Davenport Sand Mine





**Figure 2.** Davenport Dredge



**Figure 3.** Davenport Sand Plant

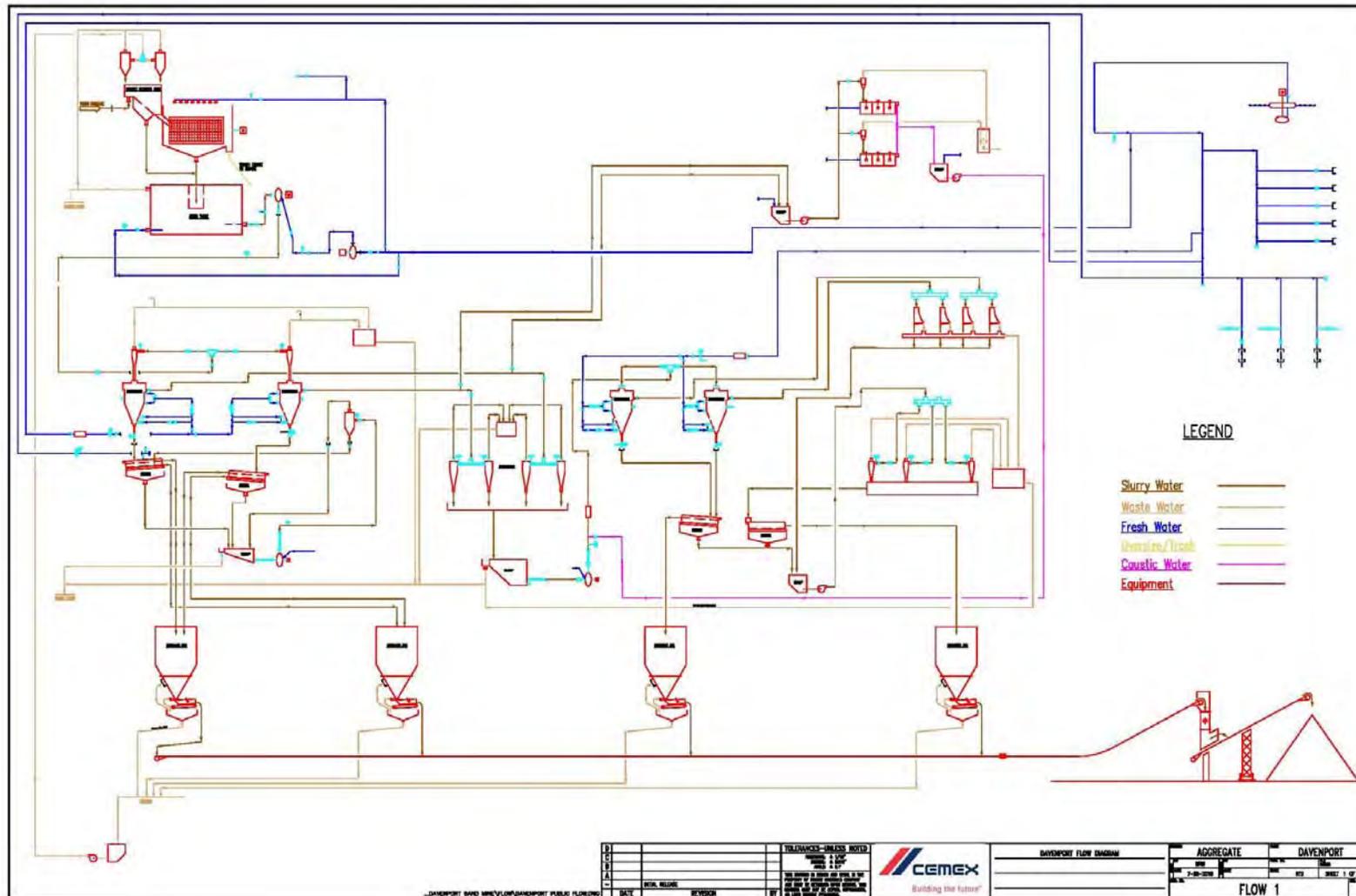


Figure 4. Generalized Flow Diagram

**FIELD TRIP LOG**  
Central Florida's Sand Mining District  
Southeastern Geological Society Guidebook No. 50  
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Begin at the intersection of Interstate 4 and US-27.  
Go South on US-27 about 10.4 miles.  
Turn Left and go East on SR-544 about 4.6 miles.  
Turn Left into **STOP 1: E. R. JAHNA INDUSTRIES HAINES CITY SAND MINE.**  
Depart Mine, turn Right on SR-544, and go West about 2.8 miles.  
Turn Left, go South on SR-17 (Scenic Highway) about 12.1 miles.  
Turn Left, go East on Mountain Lake Cut-Off Road about 0.9 miles.  
Turn Left into **STOP 2: C.C. CALHOUN, INC. PIT #1.**  
Exit Mine, turn Left, go South on Mountain Lake Cut-Off Road about 0.3 miles.  
Turn Left, go East on Burns Avenue about 2.0 miles.  
Turn Left into **STOP 3: VULCAN LAKE SAND PLANT (old Sandland Mine).**  
Depart Mine, go East on Burns Avenue/Masterpiece Road about 7.0 miles.  
Turn Right, go North on SR-17 (Scenic Highway) about 4.8 miles.  
Turn Right, go North on Eighth Street/Detour Road about 3.8 miles.  
Turn Right, go East on Bannon Island Road about 0.4 miles.  
Turn Right into **STOP 4: C.C. CALHOUN, INC. PIT #7.**  
Depart Mine, go West on Bannon Island Road about 1.0 miles.  
Turn Right, go North on SR-17 (Scenic Highway) about 0.5 miles.  
Turn Left, go West on SR-544 about 2.4 miles.  
Turn Right, go North on US-27 about 10.4 miles to Interstate 4 (point of beginning).

