FIELD TRIP ROUTE AND STOP LOCATIONS

1. Bonny Lake Reclamation Area
   W. R. Grace and Company

2. Hookers Prairie Mine
   W. R. Grace and Company

3. Agrico Camp (lunch)

4. Ft. Green Mine
   Agrico Chemical Company

Pass-by Reclamation Areas
SOUTHEASTERN GEOLOGICAL SOCIETY

Guidebook No. 19

ENVIRONMENT OF THE CENTRAL FLORIDA PHOSPHATE DISTRICT

Twenty-first Field Conference

Lakeland, Florida

December 2-3, 1977

Published by

Southeastern Geological Society
P. O. Box 1634
Tallahassee, Florida 32302
<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Officers of the Southeastern Geological Society</td>
<td>1</td>
</tr>
<tr>
<td>Twenty-first Field Conference Committee</td>
<td>1</td>
</tr>
<tr>
<td>Guidebook Contributors</td>
<td>2</td>
</tr>
<tr>
<td>Schedule of 21st Field Conference</td>
<td>3</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>4</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Peter L. MacGill</td>
<td></td>
</tr>
<tr>
<td>Hydrogeology of West-Central Florida</td>
<td>6</td>
</tr>
<tr>
<td>Sandy Nettles</td>
<td></td>
</tr>
<tr>
<td>Simulated Changes in Ground-Water Levels Resulting from Proposed Phosphate Mining, West-Central Florida—Preliminary Results</td>
<td>13</td>
</tr>
<tr>
<td>William E. Wilson</td>
<td></td>
</tr>
<tr>
<td>Natural Systems Occurring on Mined Lands of the Central Florida Phosphate District</td>
<td>15</td>
</tr>
<tr>
<td>Ben W. Breedlove</td>
<td></td>
</tr>
<tr>
<td>Radioactivity and the Bone Valley Formation</td>
<td>30</td>
</tr>
<tr>
<td>Wallace Johnson</td>
<td></td>
</tr>
<tr>
<td>The Structure, Stratigraphy and Economic Geology of the Central Florida Phosphate District</td>
<td>36</td>
</tr>
<tr>
<td>T. M. Gurr</td>
<td></td>
</tr>
<tr>
<td>A General Guide to the Stratigraphy of the Bone Valley Mining District</td>
<td>49</td>
</tr>
<tr>
<td>D. B. Crissinger</td>
<td></td>
</tr>
<tr>
<td>Road Log and Stop Descriptions</td>
<td>61</td>
</tr>
<tr>
<td>Common Fossils of the Central Florida Phosphate District</td>
<td>75</td>
</tr>
<tr>
<td>Publications of the Southeastern Geological Society</td>
<td>76</td>
</tr>
</tbody>
</table>
OFFICERS OF SOUTHEASTERN GEOLOGICAL SOCIETY

1977-78

Peter MacGill, President
Florida Bureau of Geology
Tallahassee, Florida

David P. Brown, Vice President
U.S. Geological Survey
Tampa, Florida

James Cason, Secretary-Treasurer
Northwest Florida Water Management District

TWENTY-FIRST FIELD CONFERENCE COMMITTEE

David P. Brown
U.S. Geological Survey
Tampa, Florida

T. M. Gurr
Richard C. Fountain and Assoc.
Winter Haven, Florida

D. B. Crissinger
Mobil Chemical Company
Nichols, Florida

Sandy Nettles
P.E. LaMoreaux and Assoc., Inc.
Lakeland, Florida
GUIDEBOOK CONTRIBUTORS

Ben W. Breedlove
Breedlove and Associates
Gainesville, Florida

D. B. Crissinger
Mobil Chemical Company
Nichols, Florida

T. M. Gurr
Richard C. Fountain and Associates
Winter Haven, Florida

Wallace Johnson
Department of Health and Rehabilitative Services
Orlando, Florida

Sandy Nettles
P.E. LaMoreaux and Associates, Inc.
Lakeland, Florida

William E. Wilson
U.S. Geological Survey
Tampa, Florida

Road Log and Site Descriptions

Jeff B. Brami
W. R. Grace and Company
Bartow, Florida

David P. Brown
U.S. Geological Survey
Tampa, Florida

D. B. Crissinger
Mobil Chemical Company
Nichols, Florida

T. M. Gurr
Richard C. Fountain and Associates
Winter Haven, Florida

Raymond T. Middel
Agrico Chemical Company
Mulberry, Florida

Edward R. Yopp
Agrico Chemical Company
Mulberry, Florida
SCHEDULE OF
TWENTY-FIRST FIELD CONFERENCE

December 2, 1977 (Friday)

3:00 - 4:00 p.m. ..................... Completion of registration at
Ramada Inn, 601 East Memorial
Boulevard, Lakeland, Florida

4:00 - 4:30 p.m. ..................... Introduction and business meeting

4:30 - 5:00 p.m. ..................... Hydrogeology, Sandy Nettles

5:00 - 5:30 p.m. ..................... Preliminary model results, ground-
water flow system of west-central
Florida, Bill Wilson

5:30 - 6:00 p.m. ..................... Ecological system associated with
the Phosphate Mining District,
Ben Breedlove

6:00 - 7:00 p.m. ..................... Social hour

7:00 - 8:00 p.m. ..................... Buffet dinner

8:00 - 8:30 p.m. ..................... Final Report of a Study of Radon
Daughter Concentrations in Struc-
tures in Polk and Hillsborough
Counties, Wallace Johnson

8:30 - 9:00 p.m. ..................... The structure, stratigraphy and
economic geology of the Central
Florida Phosphate District,
Mike Gurr

9:00 - 9:30 p.m. ..................... A general guide to the stratigraphy
of the Bone Valley Mining District,
D. B. Crissinger

December 3, 1977 (Saturday) Field Trip

7:45 a.m. ..................... Leave Ramada Inn, Lakeland

12:00 ..................... Lunch at Agrico Park

5:00 p.m. (approx.) ................ Return to Ramada Inn, Lakeland
ACKNOWLEDGMENTS

The Conference Committee, on behalf of the Southeastern Geological Society, gratefully acknowledges the efforts of many individuals and companies who have contributed time and talents towards a successful conference. Mike Gurr and Don Crissinger deserve special recognition for their time and effort during all phases of the field trip conference.

A special thanks is due the following companies and individuals for use of the visited properties: Jeff Brami, W. R. Grace and Company; and Raymond T. Middel and Edward R. Yopp, Agrico Chemical Company.

The Committee would also like to thank Hal Chittum, Layne-Atlantic Company, Orlando, Florida, for providing refreshments at the lunch stop.

For the Conference Committee

[Signature]

David P. Brown
Vice President
INTRODUCTION

Peter L. MacGill

The theme of this year's field trip, "The Environment of the Central Florida Phosphate District," is a reflection of the considerable interest that has been given to this area in the last several years. Not only has local interest been intense as newspaper articles and public hearings are everyday events, but state involvement and federal intervention has been obvious as DRI's (Development of Regional Impact) are common events and presidential action and national television networks are drawn to the area.

All this interest is centered around the effects on the environment in the phosphate district. More than ever before have geological scientists been involved in ascertaining those effects. Geologists have been busy in the phosphate district assessing the natural limitations that influence life such as the quality and quantity of certain natural resources like water and essential mineral deposits such as phosphate. They have also been assessing man-made limitations that arise from the impacts on the environment as a result of the methods we use to obtain those natural resources. The variety of talks that are being presented at this field trip meeting show the diversity in which geologists participate in environmental assessment. This also reflects a trend in science to view itself in a broader and broader perspective until it merges with other sciences. This holistic approach is one that unifies ideas, concepts and man.

Another objective of this field trip involves the DRI process. A DRI requires an extensive section on geology, hydrogeology and water resources of the area to be developed. The applicants, in this case the companies, have spent millions of dollars on gaining an understanding of the geologic and hydrologic character of proposed mine sites. Extensive drilling programs are run, numerous pump tests are used to evaluate the characteristics of the aquifers and detailed information is developed to determine the availability as well as the impact of water production on the area. All this is contained in the DRI which is sent to specific individuals, and city, county, state and federal agencies for approval. Unfortunately, there is no formal or informal outlet for this geologic or hydrologic data to be exposed to the geologic community. Part of the purpose of this field trip is to allow for some of that information to be presented to the geologic community and be published in a guidebook.
HYDROGEOLOGY OF CENTRAL FLORIDA

Sandy Nettles

The Central Florida Phosphate District lies within the Polk Upland and DeSoto Plain geomorphic provinces (fig. 1). These Plio-Pleistocene Age marine terraces range in elevation from 50 feet above mean sea level in southern DeSoto County up to 130 feet above mean sea level in northern Polk County. Topographic relief of these provinces is dominated by deeply incised dendritic surface drainage as opposed to Florida's more characteristic subsurface (karst) drainage. Poorly drained sandy soils with organic pans underlain by clayey sands promote surface runoff by retarding the rapid percolation of rainwater.

Five of Florida's major river systems (Alafia, Manatee, Little Manatee, Myakka and Peace) originate on the Polk Upland and DeSoto Plain. Flow is primarily west and south to the Gulf of Mexico. Quality of water in these surface waters is generally good, with bacterial concentration of maximum concern to domestic consumption. Additionally, irrigation runoff and industrial discharges with concentrations of pesticides, fluorides and nutrients may restrict the use of some of these waters for domestic, irrigation or recharge purposes.

Three aquifer systems, the surficial aquifer, Secondary Artesian Aquifer and Floridan Aquifer, are present in the Central Florida Phosphate District. Surficial terrace sands and clayey sands and sand, clay and pebble of the Bone Valley Formation comprise the surficial aquifer (fig. 2). Domestic and irrigation supplies are commonly developed from the aquifer. Water quality is generally potable and is used to recharge the Floridan Aquifer in Polk and Hillsborough Counties.

Dense plastic clays of the Hawthorn Formation separate the surficial aquifer from the Secondary Artesian Aquifer. Alternating limestone and clay in the lower Hawthorn Formation and Tampa Limestone produce potable water of rates up to 1,000 gallons per minute (gpm). A sand and clay unit is present at the base of the Tampa Limestone which forms a semi-confining layer between the Secondary Artesian Aquifer and Floridan Aquifer (fig. 3). This sand-clay unit generally thins westward and in eastern Hillsborough County and in western DeSoto County becomes a very dense gray chert (fig. 4).

Three formations, the Suwannee Limestone, Ocala Limestone and Avon Park Limestone make up the Floridan Aquifer (fig. 5). Major water producing zones are found at formation contacts and principally within highly fractured dolomite of the Avon Park Limestone. Quality of water degrades with depth and southern altitude. Hardness and high sulfate concentrations restrict use of Floridan Aquifer water quality for domestic use south of Hardee County.

Anhydrites fill much of the pore space in the Lake City Limestone which underlies the Avon Park Limestone. These evaporite deposits form an effective confining layer to the Floridan Aquifer. Wells penetrating the evaporites encounter supersaline water.
FIGURE 1
Central Florida Phosphate District

EXPLANATION

- SWFWMD BOUNDARY
- STRATIGRAPHIC CROSS SECTION

CENTRAL FLORIDA PHOSPHATE DISTRICT

Prepared by:
P.E. LaMoreaux & Associates, Inc.
A

STREAM CROSS SECTION

SEASONAL VARIATION OF WATER-TABLE

HIGH WATER

LOW WATER

WET WEATHER SINK OR POND

B

STREAM PROFILE

EXPLANATION

HIGH WATER-TABLE = HIGH BASE FLOW
LOW WATER-TABLE = LOW BASE FLOW
VERY LOW WATER-TABLE (BELOW STREAM BED) = STREAM DRY

FIGURE 2

HYDROGEOLOGIC CROSS SECTIONS AND PROFILES SHOWING RELATIONSHIP OF WATER TABLE TO FLOW OF STREAMS
FIGURE 3  Hydrologic Cycle

PREFITATION = 49 IN./YR.

RUNOFF = 11 IN./YEAR

SURFACE RUNOFF

WATER TABLE

ZONE OF AERATION

ZONE OF SATURATION

SHALLOW AQUIFER

CONFINING LAYER

FRESH GROUND WATER (SECONDARY ARTESIAN AQUIFER)

GROUND-WATER DISCHARGE TO THE SEA = 1 IN./YR.

SALT WATER

SUBMARINE SPRING DISCHARGING FROM SUBMERGED SinkHOLE

MEAN SEA LEVEL

SPRING & SEEPS

FRESH GROUND WATER (FLORIDAN AQUIFER)

PLUG

CAVERNS

EVAPOTRANSPIRATION = 37 IN./YR. BASED ON 76% OF PRECIPITATION FROM SWFWMD

POTENTIOMETRIC SURFACE

NOTE: FIGURES SHOWN ARE AVERAGES
FIGURE 4
East-West Stratigraphy of Central Florida Phosphate District

Depth in feet (mean sea level datum)
FIGURE 5
North-South Stratigraphic Section Through Central Florida Phosphate District
SIMULATED CHANGES IN GROUND-WATER LEVELS RESULTING FROM PROPOSED PHOSPHATE MINING, WEST-CENTRAL FLORIDA--PRELIMINARY RESULTS

William E. Wilson

ABSTRACT

"A digital model of two-dimensional ground-water flow was used to simulate projected changes in the Floridan aquifer potentiometric surface in 1985 and 2000, resulting from proposed ground-water developments by the phosphate mining industry in west-central Florida. The model was calibrated under steady-state conditions to simulate the September 1975 potentiometric surface. Under one development plan, existing phosphate mines in Polk County would continue to withdraw ground water at 1975 rates, until phased out as the ore is depleted; no new mines would be introduced. Preliminary results indicate that under this plan, maximum simulated recovery of the potentiometric surface is 11.9 feet by 1985 and 36.5 feet by 2000. Under an alternative plan, all proposed mines in Polk, Hardee, DeSoto, Hillsborough and Manatee Counties would begin operations in addition to the continuation and phasing out of existing mines. Preliminary results indicate that the potentiometric surface would generally recover in Polk County and decline elsewhere in the modeled area. Maximum simulated recovery is 4.5 feet by 1985 and 29.6 feet by 2000; maximum simulated drawdown is 15.1 feet by 1985 and 14.4 feet by 2000. All results are preliminary and subject to revision as the investigation continues."

---

1Wilson, W. E., 1977, Simulated changes in the ground-water levels resulting from proposed phosphate mining, west-central Florida--preliminary results: U.S. Geol. Survey open-file rept. 77-882.
ABSTRACT

Natural Systems Occurring on Mined Lands of the
Central Florida Phosphate District

by

Ben W. Breedlove and Steve R. Adams
Breedlove and Associates, Inc.
1213 N.W. 6th Street
Gainesville, Florida 32601

Replacement natural systems occurring on mined phosphate lands have received little attention. They are relatively young successional stages and are strongly influenced by the availability of seed material, substrate composition, soil moisture and land management practices.

Natural reclamation of mined areas and their rate of progression is best observed on terrestrial components of the system. Oak hammock/longleaf pine communities reoccur on many of the oldest sites. Their growth rate, following establishment, is approximately twice that of specimens from natural or unmined areas. Aquatic components of mined area systems maintain a relative immaturity, which correlates with the steep-sloped, relatively deep water bodies created by present mining techniques.

To date, reclamation practices follow the requirements and are limited to establishing slopes based on public safety considerations, leveling the terrestrial portion of the system and establishing an erosion control vegetative base. Further practices are usually devoted to achieving an immediate gain in visual appeal, or to compressing or bypassing a portion of the successional progression required for mature ecosystem establishment. The benefits that have been gained from such efforts are poorly documented. Similarly, the benefits gained from so called "natural reclamation" have not been adequately assessed.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures</td>
</tr>
<tr>
<td>1.0 CHARACTERIZATION OF PREMINING COMMUNITY TYPES</td>
</tr>
<tr>
<td>1.1 Terrestrial Systems</td>
</tr>
<tr>
<td>1.2 Aquatic Systems</td>
</tr>
<tr>
<td>2.0 LAND FORMS CREATED BY MINING AND THE ASSOCIATED SUCCESSIONAL SERIES</td>
</tr>
<tr>
<td>2.1 Hydraulic Mining Pits</td>
</tr>
<tr>
<td>2.2 Tailing Piles</td>
</tr>
<tr>
<td>2.3 Hybrid Systems</td>
</tr>
<tr>
<td>2.4 Dams and Spoil Piles</td>
</tr>
<tr>
<td>2.5 Clay Disposal Areas</td>
</tr>
<tr>
<td>3.0 GENERAL CONSIDERATIONS FOR MANAGEMENT OF MINED LANDS DEVELOPMENT</td>
</tr>
<tr>
<td>3.1 Ecological Age of Mined Lands</td>
</tr>
<tr>
<td>3.2 Seed-sources and Natural Reclamation</td>
</tr>
<tr>
<td>3.3 Control of Succession on Clay Disposal Areas</td>
</tr>
<tr>
<td>3.4 Why Restoration?</td>
</tr>
<tr>
<td>3.5 Carrying Capacity of Phosphate Land Forms</td>
</tr>
<tr>
<td>4.0 SUMMARY</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1  North Florida Natural Systems vs. Disturbed Systems.

Figure 2  North Florida Natural vs. Disturbed Systems (Rocky Creek vs. Occidental Suwannee Mine).

Figure 3  Comparative Small Mammal Trapping Success of Natural and Disturbed Communities.
1.0 CHARACTERIZATION OF PREMINING COMMUNITY TYPES

1.1 Terrestrial Systems

Terrestrial systems of the Central Florida Phosphate District include all of the major community types found in Florida. They range from relatively high and dry pinelands and xeric communities, through the relatively flat seasonally wet flatwoods, to the low lying, almost permanently saturated cypress domes, bayheads and mixed hardwood swamps. Xeric oak hammocks and wetter communities, such as floodplain forests and seepage swamps, may be considered position communities between aquatic and terrestrial systems.

Each of the recognizable vegetation associations has a characteristic, but overlapping, assemblage of animals, whose needs may be met entirely within a single community type or may require the utilization of several of the communities. In addition, each system varies in its tolerance of perturbation. Generally, all communities develop to the extent that existing or recurring environmental stress will allow. Similarly, the stage of community development on a site is indicative of the intensity of recent or ongoing vegetation or animal stress. It can be stated that as you recede from the highest and driest communities toward the lowest and wettest hydrophytic and water tolerant associations, environmental stress tends to decrease. This is indicated by the presence of more densely vegetated swamp forests among intensely used, or managed, uplands.

Isolated perched depressions within flatwoods are seasonally flooded and may frequently dry. Depending on the intensity, duration and frequency of such stress, these areas often develop non-permanent, or intermediate, communities, such as bayheads or cypress domes. A permanent or perennial flowing stream and its associated floodplain, on the other hand, may be considered a highly interdependent functional unit. In such a community, annual or frequent flooding of the associated floodplain and sweeping of detritus into the stream system provides nutrients and/or organic materials to organisms in the aquatic community.

Most of the terrestrial acreage within the Central Florida Phosphate District (CFPD) has been highly modified. Citrus, tiber production, rangeland and truck farming are major land uses which must always be taken into consideration when prescribing long-term land management objectives.

1.2 Aquatic Systems

Aquatic systems within the CFPD may be readily divided into two major, functionally distinct, groups. Perched
depressions located away from channels which are strongly pulsed by seasonal rainfall and drying are quite distinct from flowing water bodies which derive low flow discharges from bank storage or seepage areas. Lakes are excluded from consideration because of their relative scarcity in the area under consideration. Seasonally flooded, perched depressions are strongly pulsed systems with highly colored acidic, low nutrient waters. While they are part of a larger flatwoods community, such depressions are valued because water tolerant hardwoods, such as cypress and gum, grow there. Perched depressions also may contribute to the perennial flowing streams of an area. The connector channels or flowages may be poorly to well defined, and their characteristic species may be more like those of the surrounding terrestrial community than either the perched depression areas or the perennially flowing stream sections.

Perennially flowing stream systems normally have an associated floodplain, which may be vegetated by either woody or herbaceous materials. These areas and their associated hardwood covered floodplain forests are generally conceded to be zones of high productivity, requiring a relatively long period of time to be replaced.

2.0 LAND FORMS CREATED BY MINING AND THE ASSOCIATED SUCCESSIONAL SERIES

2.1 Hydraulic Mining Pits

Although hydraulic mining pits constitute a relatively small portion of the CFPD mined lands, they are a relic land form which was created by mining techniques no longer in use. They constitute a deep water resource, which is relatively uncommon in the central Florida area. They are characterized by little or no littoral or shallow water weed cover zone and so have a plankton based food chain. These pits are generally recognized as an excellent fishery resource and are also utilized for water fowl hunting. The relatively high usage received by these areas and their proven long-term usefulness as an aquatic resource may be indicative of potential uses of the deeper water bodies which could be created by future mining operations.

2.2 Tailing Piles

The stacked coarse sand fraction of the phosphate matrix separated during the beneficiation process remains quite dry for a long period of time and has a relatively poor nutrient content. Successional reestablishment upon these areas occurs relatively slow. They are typically unsuited for colonization by species from adjacent areas.
2.3 Hybrid Systems

The term "hybrid system" is arbitrary and applied to a system composed of flooded or partially flooded mining cuts resulting in steep sloped, relatively deep rectilinear water bodies. Such a system typically has land fingers and isolated spoil pile tip islands projecting into the system. This land form characteristically occurs where mining cuts have been used for waste clay disposal, and have, therefore, remained unclaimed for a longer time.

Aquatic components of a hybrid system may range from very shallow marshy areas to deep, steeply sloped water bodies, which may either be covered with vegetation or open. They are often relatively immature components, although they may acquire a more developed, marsh-like character, either when shallow and vegetation covered, or deep but vegetation covered due to outgrowth across a relatively narrow channel. As a consequence of its variability, hybrid systems are available for use by a wide variety of water fowl and other water dependent animals.

The overburden, or spoil pile material, projecting into these systems is structurally distinct from the pre-mining soils and lacks the vertical stratification typical of a natural soil. However, older mined areas are commonly covered with hardwood communities and dominated by tree species generally conceded to be natural community dominants. It is interesting to note that this relatively high degree of maturity can be achieved within 50 years after mining. This phenomenon compares favorably with recovery rates noted for temporary hardwood forest (Likens, 1978). While the diversity of the recovering system is apparently less than that of the analogous natural community, it may be that ultimate establishment of additional species is contingent upon the proximity of a source and a time allowance for successful colonization, rather than to any inherent limitation imposed as a result of mining and subsequent reclamation.

Although it is frequently stated that mining may be the primary factor controlling the reestablishment of the natural community, it may be equally true that other forcing functions, such as fire, periodic harvesting, competing seed sources, or an extremely short developmental period (in the ecological sense of time), are equally important factors determining the successional development of post-mining lands. Given the constraints that a newly created soil structure with its attendant moisture conditions and other characteristics would set, it probably is unrealistic to expect the exact reestablishment of the previously existing natural system.
Given these limited positive factors, data currently being generated which indicates wetland values, the ecological youth of the naturally reclaimed areas and a paucity of generally accepted data on which to base long-term land management decisions, our present apparent willingness to impose a set of conditions on inhabitants of the region during the 21st century is probably neither necessary or wise.

2.4 Dams and Spoil Piles

These land forms are created from overburden. Dam material is commonly obtained by transferring soil from the interior of mine cuts to their perimeter in order to increase the volume available for storage of beneficiation byproducts. All factors previously mentioned concerning the resulting soil type are applicable to this land form. Perhaps the major distinction of the dam as a land form is its possible contiguity with the adjacent natural communities along its outer perimeter. The contiguity affords a relatively wide area for contact and migration of seeds or organisms in comparison to the relatively narrow front along which re-vegetation and community development must occur on spoil pile fingers projecting into mined areas. Therefore, it could be anticipated that natural system diversity on dams would increase at a much higher rate than on spoil pile fingers. Adjacent dam areas with no intervening natural community obviously limit the rate of recovery in some areas. The required practice of mowing dams guarantees the continuance of an immature successional state until regulatory approval is granted for abandonment. At that point, a significant buildup of soil organic matter probably has already occurred and an excellent base should have been provided for the successional process to proceed.

2.5 Clay Disposal Areas

A relatively small percentage of the clay disposal areas within the CFPD has been abandoned so that the natural successional process is allowed to be reinstated. As a generalized sequence of events, clay disposal areas begin as relatively deep water bodies free from floating vegetation and with a limited littoral zone. They may contain spoil pile tips, which function as islands and therefore tend to be populated by vegetative species with floating or wind blown seeds, or those which are transported in the gut of birds or aquatic animals. Present regulations require the draining of these areas with the consequent establishment of a terrestrial community. However, they may persist for a relatively long period of time as a shallowly flooded or wet soil community dominated by wetland species.
3.0 GENERAL CONSIDERATIONS FOR MANAGEMENT OF MINED LANDS DEVELOPMENT

3.1 Ecological Age of Mined Lands

Phosphate mining in the central Florida area is a relatively new activity. Due to the increasing demand for phosphate, the majority of the mined lands are less than 20 years old. A relatively large percentage of the lands available for study are flooded and in continuing use, which has effectively arrested successional progression. Therefore, the areas available for observation of the potential recovery of natural systems is limited to a relatively small acreage and primarily to terrestrial communities.

In addition to usage as water storage areas, many of the mined lands are used at multiple points in time for storage of mining or chemical processing byproducts. Certain of the areas are also remined. This relative immaturity and general lack of aging in an ecological sense should be taken fully into account when assessing the true or lasting impacts resulting from mining operations.

Much of the adverse reaction to mined lands is a function of their appearance. Appearance is strongly correlated with the ecological immaturity of mined land, and, therefore, esthetics is an inadequate basis for assessing the potential value of these lands to support a mature, diverse natural community. Examination of the available relatively mature, sites should provide an excellent opportunity to examine the potential offered through natural reclamation and development. Such examination could lead to management procedures which have an excellent opportunity for success. We may find, as a result of such study, that present desires for immediate or fast reestablishment of hardwood communities is an unwarranted concern from an economic standpoint, that in any realistic ecological sense, a relatively short period of time has passed and that the resulting "quickly restored" community is not only much more expensive to create but the relative maturity of the naturally reoccurring and landscaped or planted system is not significantly different.

Many of the uses that can be made of systems covered by woody species are not appreciably different from the uses that can be made of systems covered by relatively easy to establish herbaceous species. Nutrient uptake and the wildlife and recreational uses afforded by marsh systems are comparable to those afforded by hardwood communities. The esthetics associated with the hardwood system are unlikely to be suitably associated with a created or restored hardwood community.
It can be shown on selected older mined areas that a relatively high degree of natural system maturity can be achieved within a century with little if any attempt to assist the restoration process. Attempts to materially improve on the process are based primarily upon achievement of a visually satisfactory system with neither a real understanding of the system to be created nor an appreciation of the relative cost of an early satisfaction of basically a socio-political requirement.

3.2 Seed-sources and Natural Reclamation

As stated previously, it is commonly observed that natural reclamation is often limited by the lack of a suitable seed source. Other requisites, if the seed source were present, such as suitable conditions for germination and growth, are no doubt also operative. The revegetation of coal mining areas and kalin mines has been significantly aided by providing mycorrhiza which assists the plants both in obtaining nutrients and in growth of root hairs. An ecological approach such as this to develop an understanding of requirements for reestablishment of natural communities is much more logical than the present agronomic and replanting approach.

Given an understanding of the limiting factors in the post-mining system and the development of low cost mining management responses to the more significant of these limitations, it becomes more likely that managed diverse communities can be reestablished with relative ease. As a consequence, it is easier to accept the probable fact that certain time constraints must be met in order to achieve given levels of system maturity. Once these factors are accepted, perhaps much of the emotional content presently injected into decision making can fade away and be replaced by an anticipatable progression toward an acceptable natural community.

3.3 Control of Succession on Clay Disposal Areas

If the successional sequence on clay disposal areas is not managed it probably remains for a relatively long period of time as a willow and primrose willow dominated shrub or brush system which may be periodically shallowly flooded and poorly drained. These species produce relatively limited amounts of fuel, shade out high fuel species and therefore preclude the possibility of fire management, which is possible with the early successional species of shallow aquatic and terrestrial systems. Both cattail and broomsedge produce high volumes of fuel on an annual basis which burn readily and could be used to control less desirable woody species. If burning were to occur on an annual basis, it is conceivable that the transition from an aquatic system to a terrestrial system would occur and progress until it is too dry for willow
to become established. Under these conditions, willow would be controlled, shading would be prevented and an early successional state could be maintained until soil moisture conditions are suitable for the establishment of woody terrestrial species.

3.4 Why Restoration?

Restoration appears at present to be a desired end product of the reclamation process particularly for wetland areas and most particularly for hardwood dominated wetland areas. The consistent demand for restoration in spite of the absence of recognized and acceptable near term restoration techniques is unrealistic except as a pressure tactic to force change. It is an approach that assumes the overwhelming importance of wetland communities in spite of the fact that most of the wetland communities, including the woody species dominated communities, have been cut over and managed toward one end or another for over 100 years. The restoration approach offers no latitude to recognize that wetlands are highly variable and therefore are neither of equivalent value nor necessarily of particularly high value. While wetland productivity may be high for certain types of wetlands, these production rates are not easily convertible to an economic or other base allowing generally understood comparisons to be easily made.

Due consideration is generally not given to the fact that systems created by mining offer appropriate soil moisture and nutrient requirements to allow a redevelopment of the primary structure and functions associated with not only wetland herbaceous but wetland hardwood communities.

Restoration requirements usually fail to consider that much of the phosphate district is not a natural system at present and that much of the so-called natural systems are either highly modified or not of particularly high value, or both. Restoration also fails to consider the need for a continuing and probably improved economic base for human activity in the phosphate district after mining has passed through and from the area. A desire to restore pre-mining conditions not only is relatively impractical but precludes the possibility, or even the concept, of new uses or resumption of old uses, particularly those of an economic nature for lands created by the mining process.

The elimination of the water retention capacity of elevated clay disposal areas is encouraged. However, these large, flat, shallowly flooded, manageable areas with relatively high spoil banks which can be used for cross dams, could possibly be used for a water based agriculture after adequate settling has occurred. Rice was one of the four major crops in Polk County during the 1890's. Rice does grow in clay based soils. Perhaps people living in the
area during the 21st century would prefer that these structures be left intact and the spoil piles stacked or left in place as a resource rather than have these areas flattened and the associated dams and spoil piles mixed back into the top clay layer. While present economic conditions afford us the excess energy to immediately restructure these systems and to impose conditions on the 21st century citizens, nothing immediately available to us allows us to determine the most suitable or easily achievable land form for 21st century area dwellers. They may well regard our present attempts at restoration as more laughable than laudable.

As a final point, "restoration" may not be desirable because new soils types are being created both by the mixing of overburden and by the creation of large clay soils areas. To my knowledge, no significant attempt has been made to examine comparable systems elsewhere or older systems occurring within the phosphate district to select either natural or managed systems components as parts of a new community type for central Florida which may offer a high esthetic appeal, have economic value and be of continuing value in the 21st century and beyond. Emphasis on restoration to pre-mining conditions seriously detracts from wiser or better use of major and distinctly new systems; they are unfortu-nately viewed, to date, primarily in terms of their imme-diately reuse and very short range spill impact potential. While spill control may be an issue warranting a significant amount of attention, it is necessary to see it in context as a short-term issue, while the future use of these areas and the development of a usable, high value natural or economic system is a long-term issue of much greater relative value.

3.5 Carrying Capacity of Phosphate Land Forms

A carrying capacity assessment of phosphate land forms is one valuable parameter for the determination of the relative value of these lands. However, such an approach presents certain problems, such as the land's relative youth, and therefore is inadequate for demonstrating these lands' true potential. Certain of the limitations can be ameliorated by selected an indicator species or a species group which is an "r" strategist. Small mammals were selected as a potentially suitable indicator species. Collections were made on mined and unmined lands in north Florida as well as lands receiving management for pine production. Both reclaimed and unreclaimed areas are included as sampling sites; although relatively short term collections were made, it is obvious that the population levels on the mined lands equalled or exceeded that of the adjacent natural communities (Figure 1 and 2).

It was doubtful whether these data could be applied to the central Florida district. Therefore, additional collections were made in central Florida (Figure 3). In addition,
UNRECLAIMED MINE
MATURE BURNED LONGLEAF PINE
ABANDONED SETTLING AREA
ACTIVE SETTLING AREA
RECLAIMED AREA
MIXED HARDWOODS
PINE - PALMETTO FLATWOODS
HIGH PINELANDS
SWAMP SYSTEMS
MATURE UNBURNED SLASH PINE
SITE PREP - LOW INTENSITY
SITE PREP - HIGH INTENSITY

FIGURE 1 NORTH FLORIDA NATURAL SYSTEMS VS. DISTURBED SYSTEMS
FIGURE 2  NORTH FLORIDA NATURAL VS. DISTURBED SYSTEMS
(ROCKY CREEK VS. OCCIDENTAL SUWANNEE MINE)
FIGURE 3

COMPARATIVE SMALL MAMMAL TRAPPING SUCCESS OF NATURAL AND DISTURBED COMMUNITIES

TRAP SUCCESS (CAPTURES/100 TRAP NIGHTS)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

North Florida Disturbed Systems
Central Florida Disturbed Systems
North-Central Florida Natural Systems

UNRECLAIMED MINE
FRESHWATER MARSH
ABANDONED SETTLING AREA
ACTIVE SETTLING AREA
RECLAIMED AREA
LAKE EDGE
MIXED SWAMP
SALTWATER MARSH
ABANDONED PINE FLATWOODS
XERIC HAMMOCK
RECLAIMED SETTLING AREA
MESC HAMMOCK
SLASH PINE FLATWOODS
LONGLEAF PINE FLATWOODS
COASTAL HAMMOCK
SAND PINE CLEARCUT
ABANDONED MINE
PONDS AND POND PINE FLATWOODS
DEVELOPED
OLDER SETTLING AREA
BAYHEAD
PONDS AND POND PINE FLATWOODS
SAND PINE SCRUB
DECIDUOUS OAK
LONGLEAF SANDHILL
ABANDONED SETTLING AREAS
PASTURE
data from the Cross Florida Barge Canal Study were selected as a major effort encompassing most of the community types common to Florida. These data were used as a background for comparison. It is obvious that the older mined areas of the Central Florida Phosphate District exhibited decreased population levels when compared to the north Florida mined systems. However, it is significant to note that these older systems must be considered better than average and all of them are within the range of values exhibited for communities monitored for the Cross Florida Barge Canal Study; because small mammals are intermediate in the food chain, many are vegetative feeders and in turn are fed on by carnivores and omnivores, their ability to establish average to better than average populations on a variety of phosphate land forms provides a relatively good indication that no major limitations accrue simply as a result of the mining process. Furthermore, it is doubtful that reclamation or land reshaping is likely to alter the significance of these results.

4.0 SUMMARY

Successional progresssion toward system maturity is better evidenced in terrestrial communities than in aquatic communities occurring as a result of phosphate mining. The relative youth and physical isolation of mined lands from suitable seed sources precludes a satisfactorily correct assessment of the potential quality of a natural system reoccurring on mined lands. Management of clay disposal areas to control domination by low value woody species has not been attempted but appears to be obtainable using fire management techniques. Restoration which fails to consider economic needs of future generations and natural system values for the various wetland types, or which fails to recognize the disturbed nature of most of the systems scheduled to be mined or adjacent to mined areas, is unnecessarily restrictive and probably unwarranted. The small mammal population levels of mined lands was in no case less than that observed for commonly occurring natural systems in Florida and on average has to be considered better than that for most of the commonly occurring natural communities in central Florida.
RADIOACTIVITY AND THE BONE VALLEY FORMATION

Wallace Johnson
Department of Health and Rehabilitative Services

Man has been exposed to natural radiation exposure for his entire history from cosmic ray activity and the presence of natural radionuclides in the earth. He did not know this until about 100 years ago and has accepted it since that time with little concern for any effects which it might produce. Natural radionuclides are found widely in nature associated with geological formations. The principal radionuclide associated with the Bone Valley Formation is natural uranium, usually occurring as an oxide (U\textsubscript{3}O\textsubscript{8}). Natural uranium is principally composed of two isotopes, i.e., uranium 238 (99.3 percent) and uranium 235 (0.7 percent). These isotopes are part of different chains of naturally occurring radioactivity. Uranium 238 is the first member of a long chain of decay products which include thorium 234 and radium 226 and ultimately decays to lead 206 which is stable. The half life of uranium 238 is long (4.5 \times 10^6 years).

The Bone Valley deposits are referred to in mining as "Matrix". This deposit ranges from less than a foot to over 50 feet in thickness. In general, matrix includes the lower two-thirds of the Bone Valley Formation. The formation is overlain by overburden to a depth of 2-50 feet. The uranium is reported to be associated with apatite, crandallite and millisite. The matrix is composed of about equal parts of phosphate nodules, clay, and quartz sand. The average concentration of U\textsubscript{3}O\textsubscript{8} in matrix is reported to be 0.0059 to 0.0094 percent. The radioactivity is not equally distributed among the constituents of matrix. Table 1 shows the concentration in various components. The greatest concentration can be seen to occur in coarse pebble (nodules) and the least in "Sand Tailings". Table 1 contains a unit which may be new to some, i.e., the Curie. This unit originally represented the radioactivity in disintegrations per second in one gram of radium 226 and is now defined as the amount of radioactive material which will produce 3.7 \times 10^7 dps. In undisturbed matrix, the various daughter products of uranium 238 are essentially in radioactive equilibrium with the parent which means that the unit "curies" is about equal for all members of the chain including specifically thorium 234 and radium 226. This is not true for weight; weight units since 1 curie of radium 226 is about 1 gram of material, while 1 curie of uranium 238 is 2.99 \times 10^6 grams of material. Because of this radioactive equilibrium, values of U\textsubscript{3}O\textsubscript{8} in pCi/gram in table 1 are approximately equal to the concentrations of radium 226 in pCi/gram.

The large volume of mining in Florida produces significant quantities of radioactive materials. Gulmond and Windham report values as shown in table 2 for marketable "rock" and various waste materials. The 1,290 curies/year uranium 238 in marketable rock represents 4,250 tons of uranium 238 per year. Gulmond reports this value exceeds the annual production of uranium 238 in mining operations designed to recover the element primarily. With the cost of U\textsubscript{3}O\textsubscript{8} greater than 40 dollars per pound, this
represents a considerable natural resource, if recovery could be effected. A process for recovery of $U_{308}$ from phosphoric acid in the manufacturing process has been developed and $U_{308}$ is being recovered at the present time.

Table 1. Uranium Content of Components of the Bone Valley Deposits

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent $U_{308}$</th>
<th>pCi/gram of Component $U_{308}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matrix</td>
<td>Average 0.008</td>
<td>22.3 (range - 17.0 to 27.0)</td>
</tr>
<tr>
<td>Coarse Pebble</td>
<td>Average 0.017</td>
<td>56.0</td>
</tr>
<tr>
<td>Leached Zone</td>
<td>Average 0.01</td>
<td>26.3</td>
</tr>
<tr>
<td>(Aluminum Phosphate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clays (Slimes)</td>
<td></td>
<td>42.0</td>
</tr>
<tr>
<td>Sand Tailings</td>
<td></td>
<td>5.3</td>
</tr>
<tr>
<td>pico = $1 \times 10^{-12}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Estimated Total Radium 226 and Uranium Activities in Florida Phosphate Mine Products and Wastes

<table>
<thead>
<tr>
<th>Material</th>
<th>Radium 226 Curies/year</th>
<th>Uranium 238 Curies/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketable Rock</td>
<td>1,300</td>
<td>1,290</td>
</tr>
<tr>
<td>Slimes</td>
<td>1,480</td>
<td>1,460</td>
</tr>
<tr>
<td>Sand Tailings</td>
<td>380</td>
<td>268</td>
</tr>
<tr>
<td>Total</td>
<td>3,160</td>
<td>3,020</td>
</tr>
</tbody>
</table>

The overburden which overlays the matrix contains concentrations of uranium 238/radium 226 of less than 1.0 pCi/gram of material. This value is roughly equivalent to concentrations found in surface soil over non-mineralized areas of Florida and it usually provides excellent shielding between the matrix and the surface of undisturbed deposits.

In the course of mining, or other activities of man which disturb this configuration, the various components of matrix containing concentrations of radium 226 of 20 - 50 pCi/gram may become mixed with original overburden producing a fill material containing a higher average concentration than did the original overburden.

The pathways by which radiation from these materials can reach man may be described as:
A. Direct radiation - exposure to gamma photons emitted by radioactive materials principally in or on the soil.

B. Inhalation - radium 226 decays into radon 222 which is a noble gas with a half-life of 3.8 days. This gas migrates through the soil toward the soil/atmosphere interface.

C. Ingestion - radioactive materials may be ingested in food and water.

Exposure to man may be increased over that originally existing by all of these pathways when average concentrations of radium 226 in shallow soil layers are increased. The term "Technologically Enhanced Natural Radiation" has been proposed to define this case.

It has been known for many years that increased radiation exposure to man occurs in the Bone Valley region. In 1965, the State Board of Health issued a report "Background Radiation in Florida" which concluded that significantly higher radiation exposure to man occurred in the region relative to other areas of Florida. In 1975, the U.S. Environmental Protection Agency studied a number of structures in Polk County and reported that structures located on reclaimed phosphate mining lands showed significantly higher exposure to inhalation of radon 222 and its radioactive progeny than occurred in structures built on undisturbed land. EPA also reported that at the highest concentrations measured, the risk of lung cancer could be expected to double in ten years for occupants of the structures.

Three new units must now be defined:

A. The rad is the unit of absorbed radiation dose defined as the amount of radiation which will deposit 100 ergs/gram of the material irradiated.

B. The rem is the unit of dose equivalent which is the dose in rads multiplied by a Quality Factor related to the kind and energy of the radiation.

C. The Working Level is a unit of exposure to the lung and is equivalent to inhalation of air at a concentration of 100 pCi/liter of radon in air in radioactive equilibrium with its short-lived daughter products (Po 218 - Po 214). A WL month represents exposure to 1 WL for a period of 170 hours. (A CWLM means Cumulative Working Level Months.)

The average radiation dose in areas of Polk County outside the Bone Valley area have been found to be:

External Gamma Exposure - 5.7 μrad/hr
Lung Exposure - 0.004 WL

Average values on reclaimed phosphate mining areas have been found to be:

External Gamma Exposure - 10.0 μrad/hr
Lung Exposure - 0.013 WL

49.9 mrem/yr
0.20 CWLM/yr
87.6 mrem/yr
0.7 CWLM/yr
The average excess exposures resulting from enhancement are then:

External Gamma Exposure 37.7 mrem/yr
Lung Exposure 0.5 CWLM/yr

The excess gamma exposure is about the same as average exposure to medical and dental x-ray procedures. The excess lung exposure cannot be related in this way but it is some 2-1/2 times the average background exposures in unmineralized areas of Polk County. The average values reported are, of course, calculated from distributions of values which have a range of values. In examining the upper limits of this range, it has been found that no individual in the Reclaimed Land category would be expected to receive an annual dose exceeding Maximum Permissible Dose (MPD) recommendations of the National Council on Radiation Protection and Measurements (NCRP) from external gamma irradiation (i.e., 500 mrem/year). This is not the case when lung exposure is evaluated. About seven percent of the structures evaluated in the Department of Health and Rehabilitative Services study on "Reclaimed" land were found to have WL concentrations such that MPD recommendations of NCRP (i.e., 1,500 mrem/year to the total lung) might be exceeded. It is estimated that more than 3,000 structures are presently located on Reclaimed land. If this is true, as many as 210 structures may be expected to have potential lung MPD in excess of NCRP recommendations.

It is interesting to note that the average WL concentration on undisturbed but mineralized land has been found to be less than 0.023 (± 0.009). This value is less precise than that reported for Reclaimed Land category but it is useful to indicate that lung exposures on Undisturbed land over mineral deposits may be as large as those over Reclaimed land. This presents an interesting dilemma in radiation protection since the MPD recommendations of NCRP are stated to be above natural background exposure. It would be possible by this logic for radiation exposure on one half-section of land to be considered acceptable while the same exposure on the other half of the section would be considered not acceptable since technological enhancement is involved.

The correlation between mineral deposits such as the Bone Valley and radiation exposure due to technological handling of such deposits is a new experience in the field of radiation protection. The Bone Valley deposits occupy an area of about 2,000 square miles which also comprise one of Florida's fastest growing population areas. The best known case involving TENR prior to that in the Bone Valley was the situation in Grand Junction, Colorado, where uranium mill tailings (up to 300,000 tons) containing about 111 pCi/gram Radium 226 were used in construction of residences and other structures. Of the estimated 18,000 habitable structures in the Grand Junction area, it is estimated that 3,600 had tailings against or under the building and 3,100 structures had WL concentrations greater than 0.014 WL.

A very important difference exists between the problem in the Bone Valley and the problem in Colorado. In the Colorado case, the elevated radioactivity was associated with a specific waste by-product of uranium milling. Increased radiation exposure was associated with the by-product
when used as a construction material. In the Bone Valley case, the elevated radiation levels are associated with enhancement of the land itself upon which structures are or may be built. Corrective measures in Colorado could involve removal of the offending material which does not appear possible in the Bone Valley since the land itself is involved. Corrective action in Florida is possible and will principally involve increasing ventilation rates in involved structures.

A more important consideration, however, will be actions to prevent increased Radium 226 concentrations during the mining and beneficiation processes. For example, 18,000 acres of land in Hillsborough County are reported to have been mined in the past with an additional mining being done or proposed on 34,000 acres. This means that about 8 percent of the total county land area is committed to past, present or future mining operations. New mining is presently being proposed in Manatee, Hardee, and DeSoto Counties where no mining has yet been done.

The study by the Department of Health and Rehabilitative Services indicates that a significant problem exists in structures presently built on reclaimed land. If we are to prevent this problem from proliferating, affirmative action is needed in the area of improved mining and land recovery techniques. Any method which would prevent the mixing of higher Radium 226 concentration strata with lower Radium 226 concentration surface strata should be considered.

The United States Environmental Protection Agency has announced that they will publish guidelines for radiation exposure in existing structures built on reclaimed land in January 1978. They will also publish in March of 1978 guidelines for unimproved land to insure that structures built on such land will not show radiation levels which exceed the guidelines for existing structures. Considerable difficulty exists in deriving such guidelines since the correlation between inside WL in structures and various land parameters is not very good. Two such parameters which EPA has considered in Draft Guidelines are outside gamma radiation levels and emanation rates of radon 222 from the soil.

Because the correlations are poor, the Draft Guidelines have been set very low by EPA to provide a conservative evaluation. These very low Draft Guidelines, if adopted, will produce significant economic impact, both from the viewpoint of corrective action in existing structures, and of use of reclaimed mining lands for future residential construction. There is general agreement that some guideline is required to provide for radiation protection. Industry, understandably, adopts the position that guidelines should be deferred until sufficient data exist to permit a rational determination of the magnitude of the guidelines.

It is a conclusion of the DHRS Report that DHRS does not have sufficient data at this time to develop a guideline for unimproved reclaimed land. A joint project involving DHRS and the University of Florida is currently trying to develop a parameter or parameters which will permit development of a rational model.
This then is the dilemma of the Bone Valley. It is many things. A significant natural resource of great economic value, an energy resource in a time of energy shortages, and a radiation hazard of significant proportions. Decisions will shortly be made which will have large impact. These decisions are social and economic as well as scientific.
THE STRUCTURE, STRATIGRAPHY AND ECONOMIC GEOLOGY OF THE CENTRAL FLORIDA PHOSPHATE DISTRICT

T. M. Gurr

INTRODUCTION

The phosphate mines of central Florida produce approximately 30 percent of the world's supply of phosphate. In 1976 Florida and North Carolina combined produced 41.6 million short tons of phosphate, or 84 percent of the U.S. output (Stowasser, 1977). For the next 5 to 10 years and at present, the most important phosphate producing region in Florida is a large shield-shaped area which encompasses vast portions of Polk, Hillsborough, Hardee, Manatee and DeSoto Counties (fig. 1). Currently, the production is from Polk and Hillsborough Counties, where ten companies operate mines and beneficiation plants in the region traditionally referred to as the Central Florida Phosphate District. During the last several years considerable activity has been underway to develop new mines and extend the district southward into Hardee, Manatee and DeSoto Counties.

These deposits are unique geologically. Unlike many of the other large deposits of the world, they do not have the typical black shale-chert lithologic association. Rather, the central Florida phosphate was deposited in a transitional, shallow water marine-to-fluvial environment. The phosphate mineral is generally a form of fluor-apatite and ranges from gravel-sized (pebble, +16 mesh) to sand-sized (concentrate, -16 mesh +150 mesh). These phosphate grains occur in a matrix of quartz sand and a varying assemblage of clay minerals which form a loose unconsolidated phosphatic clayey sand mixture. Along the Atlantic Coastal Plain in the states of Georgia, South Carolina and North Carolina, occur phosphate deposits similar in origin and characteristics to those found in central Florida.

REGIONAL GEOLOGY AND STRUCTURE

Florida lies in the Coastal Plain Geologic and Physiographic Province. In peninsular Florida the Coastal Plain is underlain principally by Cretaceous through recent sediments which characteristically thicken to the south-southwest.

In the area of the Central and South Florida Phosphate District, Cenozoic and Mesozoic Age sediments, ranging from 7,000 to 14,000 feet in thickness, rest on a Pre-Mesozoic basement of igneous and metamorphic rocks (Applin, 1951), as shown in figure 2. The Cenozoic Age sediments in this region consist of limestone, dolomite, clay and sand and range in thickness from 3,000 to 5,000 feet. The underlying Mesozoic Age sediments are sandstones, anhydrites, limestones and dolomites which vary from 4,000 to 9,000 feet in thickness.
GENERALIZED GEOLOGIC CROSS-SECTION THROUGH FLORIDA

Figure 2
The principal geologic structures in Florida, as recognized by Puri and Vernon (1964) are shown in figure 2. The Peninsular Arch is the dominant subsurface structure and forms the axis of Peninsular Florida. To the west and southwest of this major structure is the well developed Ocala uplift which forms the western margin of the peninsula. Vernon (1951) refers to the Ocala uplift as an elongate dome trending northwest-southeast and plunging southward. Cathcart (1963a) recognized the possibility of a small southwest trending anticline in southeastern Hillsborough County and referred to it as the Hillsborough high. Stress relief faults related to these structures are known in the region of the Central Florida Phosphate District, some with considerable vertical displacement (Cathcart, 1963c).

LOCAL GEOLOGIC SETTING

General

The deposits of the Central Florida Phosphate District and its southern extensions (fig. 1), occur as a thin blanket of sediments on the southern flank of the southward plunging Ocala uplift (fig. 3) and range in age from middle Miocene through recent. Abundant vertebrate and invertebrate fossils were described in the section by Riggs and Freas (1965).

The Bone Valley Formation, the principal phosphorite horizon in Polk and Hillsborough Counties, was originally named by Matson and Clapp (1909) as the Bone Valley gravel (from Cooke, 1945). Cooke dropped the descriptive term gravel in favor of the more general term formation, since the gravel makes up only a small portion of the deposit.

Further south, principally in Manatee, Hardee and DeSoto Counties where the Bone Valley formation is locally absent (Cathcart 1963b), the upper member of the Hawthorn formation forms the major zone of commercial phosphate.

Origin of Deposits

Numerous origins have been suggested for these deposits. One theory suggests that the phosphate was derived from quano deposits of bird rookeries (Vernon 1951). Another is that phosphate precipitated from a shallow tropical sea overlying a broad carbonate platform. This idea proposes that cold, phosphorous rich water upwelling from the ocean depths was warmed in the shallow water zone precipitating phosphorous. From these phosphorous rich waters, phosphate crusts and pellets were deposited. These crusts and pellets of phosphate were in some instances later reworked and redeposited in concentrated deposits (Freas and Riggs, 1968).

The richest deposits of phosphatic sediments, as suggested by Cathcart (1968), appear to have formed in basins that are associated with structural highs. In central Florida the Ocala uplift and the Hillsborough high are the principal controlling structures.
Figure 3. Cross-Section A-A'. Structural relationships of the post-Eocene rocks of the Central Florida Phosphate District. Cross-Section is located in Figure I (after Altschuler, et al, 1970, Figure 2).
Much of the phosphate appears to have been deposited during the Miocene time and was in many areas reworked and redeposited in Pliocene to Holocene times. The phosphatic sediments seem to have been deposited in warm shallow seas generally near shore. Fossil assemblages associated with most of these sediments give strong support to the proposition of cyclical inundation and regression by the sea.

Hawthorn Formation

The Hawthorn formation in this region consists of two members -- a lower tan and yellow phosphatic sandy and argillaceous, dolomitic limestone which is the "bedrock" in the mines and an upper green clayey sand member which occurs down dip in Hardee, Manatee and DeSoto Counties and only locally in Hillsborough and Polk Counties.

Lower Member

In the active mining district of Polk and Hillsborough Counties, the irregular surface of hard, yellow or tan sandy dolomitic limestone exposed in the floors of mining pits is generally the natural boundary between the Hawthorn and Bone Valley formations (fig. 4). The upper surface of the Hawthorn is irregular and marked by solution features (Altschuler, et al, 1964).

Cathcart (1963a) reports that the top few feet of the Hawthorn often consists of a recemented or weathered solution breccia, rich in residual sand, phosphate and carbonate pebbles, and internal molds of fossils. He states that the mid-Miocene Hawthorn formation is an impure marine limestone containing many broken fossils, abundant quartz sand and silt, and montmorillonite clay. He further notes that the Hawthorn formation is also characterized by phosphorite low in percent $P_2O_5$.

The Hawthorn on the western side of the Central Florida Phosphate District was deposited in relatively shallow water on the flank of the rising Hillsborough high (Cathcart 1963a). In most of the active mines the contact with the Bone Valley and the Hawthorn is generally marked by a residual calcareous clay which is gray, gray-blue, gray-green, yellow, cream, or brown and contains abundant fine to medium-grained quartz and phosphorite sand and trace amounts of phosphorite pebble. This "bedclay", as it is called by the miners in the district, is texturally similar to the limestone and according to Cathcart (1963a) is probably the result of at least two chemical weathering cycles, one due to the areal exposure of the Hawthorn in the late Miocene, and the other related to the later intense lateritic weathering of the Bone Valley. The Hawthorn bedrock contains varying amounts of interbedded green clays, phosphorite and quartz sand, and silt.
Down dip, principally in Hardee and Manatee Counties, the lower carbonate member of the Hawthorn is generally similar to that observed in Polk and Hillsborough, however it tends to contain more chert and commonly has a thick sequence of dense overlying clay.

**Upper Member**

The upper member of the Middle Miocene Hawthorn formation is identified by Cathcart (1963b) as a "green to blue clay interbedded with sandy clay or clayey sand containing brown or tan phosphate nodules". Exploration drilling in this region has shown that this phosphatic clayey sand unit commonly contains interlayered beds of shaley clay and dolomitic limestone (fig. 5). This upper sandy zone of the Hawthorn is the primary ore zone in the southward extension of the Central Florida Phosphate District.

**Bone Valley Formation**

Disconformably overlying the Hawthorn formation is the Plio-Pleistocene Bone Valley formation. The most popular theory of the origin of these sediments, as summarized by Altschuler, Cathcart, and Young (1964) is that "The Bone Valley Formation is a shallow-water marine and estuarine phosphorite of Pliocene age... (It)... is an excellent example of marine transgression during which the phosphate was derived, by reworking, from the underlying, weathered, Hawthorn formation." In the Bone Valley formation, sharks teeth and skate grinding plates are the most prevalent fossil remains of marine life noted. Interbedded with this sequence are found the remains of Gavial (alligator), Sirenian (seacow), horse, rhinoceros, camel, and other animals (Fountain, 1969).

As described by Altschuler (et al, 1970) the Bone Valley formation, the principle phosphorite horizon, in Hillsborough and Polk Counties, is composed of two major units; a lower marine unit of bedded, argillaceous, phosphorite and quartz sand, and an upper unit of massive bedded or finely graded-bedded, argillaceous sand with only minor or trace amounts of phosphorite present in the upper beds. The lower unit of the Bone Valley contains thicker and coarser graded sets than the upper unit. Crossbedding is also more common in the lower unit.

The sediments of the Bone Valley formation are generally represented by equal amounts of apatite (carbonate-fluorapatite), clay (predominantly montmorillonite), and quartz (with minor chert). However, over small distances the proportional amounts of these components may change considerably.

The Bone Valley sediments as exposed in the phosphate mines of this area consists in general of light tan to light gray to medium gray or green, massive to finely graded and crossbedded, firm, argillaceous, sub-
GENERALIZED GEOLOGIC SECTION IN THE SOUTHERN PORTION OF THE CENTRAL FLORIDA PHOSPHATE DISTRICT

FIGURE 5
to well-rounded and polished, coarse to fine-grained, white, tan and brown phosphorite and quartz sands.

As a result of the blanketing of the Bone Valley by the Pleistocene (?) mantle of loose quartz sands, natural outcrops of phosphatic sediments are rare and are found most commonly along deeply incised stream channels.

**Pleistocene and Holocene Series**

The Pleistocene of the central portion of the state is generally represented by the mantle of loose quartz sand which blankets the area. These loose sands are considered to be of various origins. Altschuler and Young (1960) consider these sands that overlie the Bone Valley Formation the insoluble residue of the lateritic weathering of the Bone Valley, not the result of transgressive Pleistocene seas. However, they do admit that a few channel and dune deposits of Pleistocene and Holocene age may exist but that this is a thin veneer of only local importance. Others, however, tend to consider the origin of these sands as the result of primary deposition. Cathcart (1962) favors a Pleistocene deposition for these sands. Pirkle and his associates also suggest a primary depositional origin for these surface sands. According to Pirkle (1965) the surface sands are not the result of the weathering in situ of the Bone Valley sediments as suggested by Altschuler and Young (1960).

Fossils taken from a drainage ditch northeast of Fort Meade at the Poole Branch site date the surface sands at that location as Pleistocene in age (Pirkle, et al, 1967).

These loose Pleistocene sands crop out at the surface of the phosphate district except for those portions that are covered by Holocene materials consisting of accumulations of organic debris, and clastic materials reworked by rainwash and streams.

**Pleistocene Terraces**

Cooke (1945) identified seven Pleistocene shorelines in Florida. MacNeil (1950) recognized four terraces at elevations of 150 feet or lower. Those terraces above the 150 foot level MacNeil feels cannot be definitely related to the Pleistocene shorelines. Vernon (1942) recognized four terrace deposits of the Pleistocene interglacial stages. Pirkle (1964) and (1970) also supports the view that several terrace deposits of Pleistocene age exist below the 150 foot elevation. The terrace deposits of Florida as recognized by various workers are summarized in Table I.

Altschuler and Young (1960) disagree with the occurrence of Pleistocene shorelines in the land pebble phosphate district stating that the grain-size distribution of the surface sands is completely independent of the previously proposed shoreline terraces.
In the Central Florida Phosphate District, the phosphate ore or matrix is mined by large walking draglines and ranges in thickness from less than 5 feet to greater than 45 feet. The average thickness of the ore is 15 to 25 feet (fig. 4). The overburden thickness in the mining areas is 10 to 50 feet. The phosphate pebble product (+1 MM or +16 mesh) is recovered by washing and screening. The sand-sized phosphate material or flotation feed is generally -1 MM to +0.1 MM or -16 mesh to +150 mesh in size. Minable flotation plant feed ranges from 12 to 14 percent BPL (5.5 to 6.4% P₂O₅) in the lean areas to 35 to 40 percent BPL (16.0 to 18.3% P₂O₅) in the richer areas. However, the average range for flotation feed is 22 to 28 percent BPL (10 to 12.8% P₂O₅).

The phosphate pebble generally ranges from 66 to 70 percent BPL (30.2 to 32.0% P₂O₅) and the sand-sized phosphate concentrate ranges from 72 to 78 percent BPL (33.0 to 35.7% P₂O₅). The 76 to 78 percent BPL concentrate is rapidly diminishing in supply.

The average matrix or phosphate ore consists of one-third phosphate, one-third quartz sand and one-third clays. The phosphate ore averages 8,000 to 15,000 tons per acre of recoverable product.

In the south Florida extension of the district, the overburden thickness is often much greater, ranging from 15 feet to over 100 feet (fig. 5). The matrix is also often much thicker, ranging from 35 to 80 feet, and consists of fine to medium grained poorly sorted phosphatic clayey sands and phosphatic sandy clays which are generally finer than the deposits further north in the central district.

The beds of shaley clay and dolomitic limestone which are common in the sandy portion of the upper Hawthorn are a major source of contaminants to the phosphate products. In many deposits or areas the phosphate pebble is so high in carbonate particles (especially magnesium carbonate) that it must be rejected. The sand-sized flotation feed is on the average much lower in BPL ranging from 12 to 18 percent (5.5 to 8.2% P₂O₅). In addition, in many of the deposits currently considered minable, the sand-sized phosphate concentrate is much lower in grade than in the central area, ranging from 66 to 70 percent BPL (30.2 to 32.0% P₂O₅).

**SUMMARY**

For the last several years the mines in central Florida have produced 30 percent of the world's supply of phosphate. The sedimentary deposits from which the phosphate is mined range in age from Mid-Miocene through Pleistocene and occur as a thin veneer on the southern flank of the southward plunging Ocala uplift.

The Bone Valley formation, a shallow water transitional marine to fluvial Pliocene-Pleistocene phosphatic clayey sand, is the primary phosphate ore zone in the current producing district in Polk and Hillsborough Counties.
In the southern portion of the district in Manatee, Hardee, and DeSoto Counties, a clayey sand upper member of the Mid-Miocene Hawthorn formation is the primary phosphate bearing strata. The lower portion of the Hawthorn formation is an impure phosphatic dolomitic marine limestone, marking the lower boundary for mining in the northern portion of the district and the basal unit for phosphate exploration in the southern portion of the field.

These phosphatic sediments are covered by a blanket of clayey sands, clays and sands of Pleistocene to Holocene Age, which were shaped by glacial sea level fluctuations and incised by streams.

The phosphate produced by the Central Florida Phosphate District ranges in size from gravel (pebble) to sand (concentrate) and averages 66 to 74 percent BPL. The average thickness of the clayey sand phosphate matrix or ore zone averages from 15 to 25 feet and is overlain by 10 to 50 feet of non-phosphatic overburden sands and clayey sands.

In the southern extension of the Central Florida Phosphate District the ore zones contain interbedded lenses of dolomitic limestone and shaley clay that contaminate the phosphate pebble so that in general it must be rejected as waste. The primary product expected from the southern field is sand-sized phosphate concentrate which is lower in percent BPL (66-70) than the concentrate from the areas in the central district to the north. The overburden and matrix ore zone commonly is much thicker than in the central district ranging from 15 to 100 feet and 35 to 80 feet, respectively.

LIST OF REFERENCES


A GENERAL GUIDE TO THE STRATIGRAPHY OF
THE BONE VALLEY FORMATION

D. B. Crissinger

ABSTRACT

The phosphate deposits of Polk, Hillsborough, Hardee, Manatee and
DeSoto Counties were formed in what appears to be a shallow marine envi-
ronment. Depositional trends indicate that numerous small transgression-
regression sequences have occurred since the middle Miocene, "Hawthorn",
time.

It is the belief of the author that a number of marker beds exist
in the active mining district that can be of some help in stratigraphic-
ally correlating areas. These marker beds vary from one area to another
and it is not uncommon for many, if not all of them to be missing from
a given geologic section. Ten of these units are described in the paper
presented and they are related to present topography, local structure,
vertebrate fauna, and their north-south position in the phosphate field.

There is no attempt made to establish a definite stratigraphy for
the phosphate district. The intent of these correlation units is merely
to establish a set of commonly occurring beds, which seem to bear the
same fauna and general characteristics, that can be related to the other
stratigraphic units present in an area.

Included in the paper is a common index fossil for each of the units.
While it is possible to collect some of these genera and species from
other stratigraphic positions, the given index fossil occurs with a fre-
quency that indicates the depositional time and or environmental charac-
teristics favored preservation of the index fossil. A good example of
this is the Pliocene horse Neohipparion eurystyle. This horse ranges
throughout Bone Valley time and can be found in most of the strata listed
as at least a minor part of the terrestrial fauna. The listing as an
index fossil for Unit "3" is because it is the most consistently abundant
terrestrial element found in that unit. There is enough reliability in
these index fossils that if you desire a given specimen, it can be found
with considerably less effort by collecting the indicated unit.

Listed below is a brief summary of the ten units listed in the
author's paper, starting with the oldest:

"0" Unit "0" is the Hawthorn Limestone. Particularly the dense, dolo-
mitic limestone phases containing only a trace of phosphate and no
terrestrial fauna.

"1" Unit "1" is a less consolidated overlying phase of the Hawthorn that
contains more phosphate, sand, and clay than the true dolomites and
limestones. The index fossils are the horses Merychippus and
Calippus sp.
"2" Unit "2" is the traditional "bed clays" normally considered to be Hawthorn in age. They consist of silty clays, often earthy in appearance, that are a residuum deposit. Common terrestrial index fossils are the horses Calippus sp. and Hipparion plicatile.

"3" Unit "3" is a sandy lower matrix, Lower Bone Valley pebble zone. The unit is sandier and contains much more pebble sized phosphate than the bed clays. The most common horse is Neshipparion eurystyle.

"4" Unit "4" is a sandy middle matrix, Lower Bone Valley phosphate strata. This "Feed Zone" almost always yields more sand sized phosphate than pebble sized phosphate. The fauna is marine and the most common fossil is the Pliocene durgong Felsinetherium floridanus.

"5" Unit "5" is a clayey upper matrix, Lower Bone Valley pebble zone. The sand size fraction is much reduced, increased clay, and the pebble phosphate is light colored and more abundant than the sand sized phosphate. The most common terrestrial fossil is the Pliocene horse Nannippus ingenrusu.

"6" Unit "6" is a current reworking of the matrix that is usually very sandy and pebbly linear channel deposits. This is the uppermost unit of the Lower Bone Valley formation. The phosphate pebble yields are usually extremely high while the sand sized phosphate yields are normally lower due to sand dilution. While there is no reliable terrestrial index fossil for this strata, many genera are often abundant, occasionally a horse of the lowermost Pleistocene, Nannipul phlegon, can be found in this unit.

"7" Unit "7" is the Upper Bone Valley formation, or leach zone, common to the active mining district. It is formed by the effect of ground water chemically breaking down the clay and phosphate minerals.

"8" Unit "8" is a series of sand zones overlying the leach zone that show several modes of origin. They are normally relatively clean sand and clayey sand units.

"9" Unit "9" is the "A", "B", and "C" soil horizons that contain respectively, organics, leached sands, and ground water enrichments such as hardpan and ground water podsols.

"10" Unit "10" is a stream deposit in modern lows that consists of mixed beds of muck, clays, and sandy phosphate pebble zones. Some of this material was dredge mined early in the century and was known as "River Pebble" phosphate. The best known terrestrial fossil from these deposits is the Pleistocene horse Equus sp.
INTRODUCTION

The central Florida phosphate mining district has produced an infinite number of interesting geological sections and there are many papers and publications available describing the origins and stratigraphy of the Bone Valley Formation. It is apparent though that most of the authors did not have the time, opportunity, and good fortune to follow the mining areas in detail over a number of years. And the very complex stratigraphy of the phosphate field can be overwhelming to the uninitiated. Some of these gaps between the excellently described stratigraphic sections may never be understood, but it is the belief of this author, after some years of observing this mining in many areas, hundreds of miles of walking cuts, collecting in-place fauna, and discussing this collected data with geologists from different companies, that there is a set of general stratigraphic relationships in the active mining district. The purpose of this paper is not to establish a definite stratigraphy for the Bone Valley area, but rather to stress the fluidity of the phosphate horizon and trends which seem to supply some order to the chaotic bedding.

The general geology of the phosphate district was discussed in the preceding paper. There is a movement in vertebrate paleontology at this time to drop the Bone Valley Formation back into the upper Miocene in an attempt to better correlate North America with worldwide faunas. In order to avoid confusion, this paper will consider the Hawthorn and Bone Valley Formations in the manner accepted for many years in the phosphate district.

The phosphate deposits of Polk, Hillsborough, Hardee, Manatee, and DeSoto Counties were formed in what appears to be a shallow marine environment. Depositional trends indicate that the area was a large embayment with the sea shoaling some distance north of Plant City and Lakeland. Several theories have been advanced on the origin of the phosphate beds, such as direct precipitation, residual deposits, guano, and supergene enrichment of limestone fragments, but the district seems to offer stratigraphic sections to prove, refute, and modify all of these categories. Figure I presents a composite of a typical stratigraphic section. Each of the units, "0" through "10", will be discussed starting with the oldest.

-0-

Unit "0" is the Hawthorn Limestone which is an extra firm, hard, or dense, compact, massive dolomite limestone to argillaceous dolomitic limestone. The color varies from white to yellow, tan, and less often grey. This unit normally contains a trace of fine sand-size phosphate that is amber, tan, brown, or black in color. The unit often contains the casts and molds of Miocene marine shells. Although the unit consists of lenticular beds, it may locally be considered massive in practical terms because it is very difficult to get exposures large enough to see the limits of the strata. This unit is not exposed at all mining locations but can usually be found when the ditch in the pit bottom is deep and dry,
FIGURE 1
TYPICAL CROSS SECTION

Note: Vertical slopes exaggerated by the scale

Economic mining limits

Unit number 6
Sand —
Clay —
Pebble —
Limestone —

Conformable Contact
Diastem Contact

Uplands

Lowlands

Stream

Overburden Base Rock
particularly at a low structural elevation. Some areas show this unit interbedded with sandy and/or clayey phosphorite stringers when a prospect hole penetrates it. The unit appears to be barren of terrestrial fauna and the mollusks indicate that it is normally a middle Miocene to upper Miocene age. It is likely that it represents a shallow stand of the sea when phosphate deposition was just starting to become an effective mechanism. The underlying, at some depth, Tampa Limestone has provided some terrestrial fauna in the Tampa area including the small horse, Parahippus blackbergi, indicating the possibility of a low sea level stand prior to the lowermost Hawthorn deposition. There seems to be a general trend in the phosphate field that the lower portions of the Hawthorn Formation are a cleaner limestone/dolomite and contain less phosphate granules and clastics.

-1-

Unit "1" is essentially a sandy Hawthorn unit. It contains more sand, silt, clay, and phosphate than Unit "0". It can consist of sands or sandy phosphate zones interbedded with dolomite stringers, or it can actually be a silty to sandy clay containing varying amounts of sand-sized phosphate. There are several characteristics which help identify this unit.

North of the Polk-Hardee County line the unit contains more attapulgite clays than the surrounding units. The normal colors for this strata are black, blue, grey blue, grey green, or occasionally yellow or calcareous mottled green. The unit's color is often affected by the reducing environment sulfides and organics, and the strata often changes color upon exposure to the air. The northern unweathered exposures are often subtranslucent to gelatinous, slippery or soapy feeling, or very tacky when the present solids are low. These characteristics usually reflect the attapulgite content of the individual unit.

South of the Polk-Hardee County line there is no mining activity at this time but a great many drill cores have been inspected. It appears that the unit is occasionally similar to its northern equivalent but, a transitional facies change, or down dip equivalent, occurs. The trend is for a drop in the clay content with an increase in the sand-size material. These clayey sand beds appear to be widespread, lenticular, near shore deposits of varying thickness and phosphate content. Colors vary from light greenish grey to black clayey sands with the coloration usually being determined by the phosphate granules, organic, and calcareous contents rather than the clay content. The drill cores show a sparse but highly reworked terrestrial fauna and an abundant shallow marine fauna, part of which shows little reworking. It appears likely that this material is partially reworked in place including residual material, with some clastic influx from the nearby land mass.

The age of unit "1" is quite variable and it appears that the strata represents various remnants of the early phosphatic depositional and erosional stages. Some exposures show diastems and it is apparent in most
exposures that some sort of physical sorting and/or nutrient enrichment occurred at the time of deposition. The gently rolling topography of the top of the Hawthorn limestone/dolomite allows unit "1" to frequently be cut or altered by weathering and this alteration, particularly in the northern areas, can make the unit indistinguishable from the bed clays. Occasionally a terrestrial fauna can be collected from this unit in the northern district and the fauna varies from the middle Miocene into the lower Pliocene.

The distribution of this terrestrial fauna is heavily in favor of the lower Pliocene and the different ages of fauna normally occur at different locations that cannot be easily correlated with each other. A good enough stratigraphy appears present to assert that the northern region began shoaling with a few preserved exposures in the middle Miocene that are best represented by the horse *Merychippus*. The preservation of terrestrial exposures increases towards the Pliocene and the entire region could have been completely emergent in lower Pliocene time. This lower Pliocene fauna is best represented by the horse *Calippus* sp. It is apparent that most of the preserved fauna is shallow marine to intertidal and that terrestrial deposits are the minority. Later reworking, erosion, and weathering has removed most of the upper portions of this unit from the uplands. In the northern areas, the best exposures occur as remnant highs in structural lows that are usually modern stream beds. These isolated highs in structural lows appear to have been literally passed over by later reworking. They do not normally have a protective cap-rock and their location seems to be random within the lows. Ancient and modern streams have eroded some of these deposits and it appears that this mechanism is still actively removing the scattered remnants. South of the Polk-Hardee County line the lower structural elevations allow this unit to become massive and widespread with thicknesses in excess of 60 feet at some locations.

Unit "2" represents the traditional "Bed Clays". It usually consists of firm or extra firm clays and silty clays containing minor amounts of fine sand-sized phosphate, or less often pebble phosphate. The fauna is normally marine to intertidal and often represents material similar to that in the underlying strata. The age of the bed clay can thus appear to be that of the underlying units, but this is usually an erroneous conclusion. Studies of hundreds of interfaces and stratigraphic relationships indicate that the bed clay definitely overlies or alters units "0" and "1" and that unit "3" definitely erodes and overlies unit "2". The nature of this stratigraphy indicates a normal range of upper Miocene to the middle Pliocene period. A chemical weathering of the underlying units appears to be the predominant origin of the bed clays. The overwhelming fauna in the bed clays suggest a marine or shallow water origin. But, it is apparent that great weathering occurred at this time and the presence of solution channeling and sinkholes containing only units "2" and/or "3" indicates very effective chemical erosion in this time frame. It is likely that there was a prolonged emergence in bed clay time and that active chemical
erosion and later reworking and erosion has effectively removed most of
the terrestrial fauna. The distribution of the bed clays is widespread
and they extend at least to the present mean sea level in the southern
district. Although intact terrestrial faunas are difficult to find in
the bed clay, they are probably best represented by the horses Calippus
and Hipparion plicatilis. This indicates that at least some of the ter-
restrial fauna believed to lie in unit "1" may actually be in slight al-
terations that represent unit "2". Most bed clays show a good transitional
alteration downward into the parent formation and it is not uncommon for
bed clays to exhibit an oxidizing mineralogy. The upper contact of the
bed clay is often a corrosion zone showing active reworking upward of
clay chips and the harder particles. This provides a strong argument
that a transgressing sea moved onto the bed clay. The normal clay min-
eralogy of the bed clays tends to be calcareous mixtures of attapulgite
and montmorillonite. The dolomitization of the underlying Hawthorn prob-
ably began during the prolonged exposure that must have occurred during
bed clay time. Normal colors for the bed clay are tan, reddish brown,
white, grey and grey green. In the classical sense, this unit is Hawthorn
in age.

---

Unit "3" is a sandy lower matrix pebble zone. The unit often shows
thorough reworking and rubble zones on the bed clay/bedrock contact. This
unit can have exceptionally high yields of phosphate pebble. The phosphate
pebbles are usually low grade. Some areas exhibit very shiny, small, dark
pebbles of phosphate but the normal trend is for coarse sizes of dark
phosphate which contain clay and dolomite inclusions. It is not uncommon
for the larger particles in this strata to show positive evidence of the
phosphatic replacement of limestone fragments. Most of the fauna is shal-
low to deep marine but there is a persistent terrestrial element through-
out the areal distribution of this strata. This fauna can often be traced
to the reworking of older units. Thus it can seem to be a stereotype of
a transgressing sea.

Unfortunately, this is complicated by the persistent occurrence of
Neohipparion eurystyle, a well known Pliocene horse. Apparently there
were also widespread intermittent terrestrial exposures during this general
transgression.

The degree of development of unit "3" shows a definite correlation
to the structural elevation of a location. High elevations in a given
region show a stronger development of unit "3" than the lower elevations
which show a much reduced or missing section. This fits the transgression
model very well since it would be expected that greater reworking and rub-
ble zones would occur on structural highs. It is not uncommon for this
strata to completely fill large sinkholes that existed at that time,
creating very high phosphate pebble tonnages in small areas. The normal
colors for this unit are dark mixtures of black, brown, grey, and less
often grey green. The relative abundance of pebble phosphate often dominates the color of the unit more than the clay type. This unit is less calcareous than "0", "1", and "2" and often shows its best development in areas where the bed clay is missing or much reduced in section by reworking. Unit "3" is normally considered to be a part of the Lower Bone Valley Formation.

---4---

Unit "4" is literally the middle matrix sandy zone. It consists of sandy clay to clayey sand mixtures of fine grained phosphate. Even in the strongest developed pebble deposits this unit, if present, usually yields more sand-sized phosphate than pebble phosphate. The intact fauna has in the author's experience always been marine. The most common fossil in this strata is the Pliocene dugong Felsinotherium floridanus. Although this is the most common "Bone Valley" fossil, it has been the author's experience that the majority of the in-place specimens usually come from unit "4". The virtual absence of terrestrial fauna in this strata supports the transgression sequence of unit "3" by showing a prolonged submergence and deeper water/lower energy sedimentation conditions. The color of this unit is quite variable and is more or less dependent on the region a given section is studied in. The normal colors are black, grey, grey green, green, white, tan, pink, lavender, and iron-stained reds and browns. Predictably, the unit is quite susceptible to supergene enrichment and normally yields better grades of phosphate than the underlying units. It is not unusual for the lower boundary of this unit to be conformable and upper limit of the sandy zone usually shows a sharp diastem or some degree of reworking. At one location, just west of Fort Meade in Section 29-31-25, the author observed a well preserved paleo-soil and leach zone marking the upper contact of this unit at elevation 116 feet MSL. Thus, it is likely that a general regression started and as unit "5" deposition began, terrestrial exposures of the upper parts of unit "4" may have occurred. The position of this unit between units "3" and "5" dates it as being middle Pliocene and it is considered part of the Lower Bone Valley Formation.

---5---

Unit "5" is an upper matrix pebble zone. The strata is usually a green or grey green clay to sandy clay containing traces to abundant white, cream, tan or light brown phosphate pebbles. In some areas acid leaching further alters this matrix color to light grey, white, or iron-stained reds and browns. The clay content of this unit is often high and the normal clay mineral is montmorillonite. The unit is often stiff or blocky due to the mineralogy and high clay/low sand content. In many respects, this strata represents a low energy environment similar to an embayment.

The fauna in unit "5" is variable but the marine to shallow marine influence normally dominates the fauna. The presence of whale material and large shark teeth implies that there was at least intermediate water
depth in some regions. In many areas, particularly at the higher elevations, this unit yields a persistent terrestrial fauna. The most diagnostic member of the terrestrial fauna seems to be the Pliocene horse *Nannippus ingenuus*. While terrestrial fauna can be found at any level within unit "5", the author's experience indicates that the majority of the specimens come from the upper 18 inches of the unit. Evidence is present to indicate that some of the terrestrial fossils have "settled" downward in the clay with time. This does not explain the occurrences at the lower levels but the indications are that a greater degree of emergence occurred in late unit "5" time. A good model of this unit may be the present shallow embayments and tidal flats or mangrove swamps along Florida's west coast.

The distribution of unit "5" is spotty throughout the Polk and Hillsborough County phosphate district. Many of the areas that seem to be missing unit "5" will show that it was possibly once there, and has been leached out to the extent that it shows as vugs, where the phosphate pebbles were, in the aluminum phosphate cemented sand "Sandrock" of the overlying leach zone.

It is difficult to distinguish unit "5" in the southern district due to a compressed section of reworked units "3", "4", "5", and "6". This down dip Bone Valley equivalent is normally only a few inches to feet thick and overlies unit "2" in much of Hardee, Manatee, and northern DeSoto Counties as a spotty occurrence. The terrestrial fauna in this down dip equivalent predictably ranges from lower Pliocene up into the Pleistocene indicating numerous episodes of reworking.

This unit represents a water, stream, and/or current reworking of the matrix. The normal occurrence of this unit consists of linear channel like lag pebble deposits gouging into the matrix. These channels often exhibit mixed marine, fresh water, and terrestrial faunas. The shallow marine influence seems to dominate most of these deposits. Some of the fauna has obviously been reworked and brought stratigraphically upward into unit "6".

The unit is usually a light grey, buff, or dark pebbly sand or clayey sand and the variance of the color from light grey usually depends upon the color and abundance of the phosphate pebbles in the matrix. The sizing in this strata is usually coarse grained and pebbly. The sands appear frosted to the naked eye and the clays can be leached kaolins or montmorillonites. It is not uncommon to find some small quartzite pebbles and occasionally quartzite cobbles can be found in unit "6", indicating high energy levels.

The origin of unit "6" seems to be initially an etching of the matrix by tidal channels during a regression. As the regression progressed, these channels evolved into estuaries and ultimately some became fresh water streams containing terrestrial fauna. It appears that the phosphatic depositional cycle had stopped about the time unit "6" began forming and primary deposition was either minimal or nonexistent in unit "6" time.
The age of unit "6" is usually Pliocene but occasionally a Nannippus phlegon, a horse of the lower most Pleistocene, can be found in the terrestrial fauna. Unit "6" is the uppermost strata of the Lower Bone Valley Formation.

-7-

Unit "7" is the leach zone created by natural acid leaching of the matrix. Although leaching has occurred intermittently since the middle Miocene, the bulk of the destruction of the northern zone seems to have occurred during the upper Pliocene to lower Pleistocene. The leaching consists of the chemical breakdown of clays and phosphate. This creates kaolin clays and iron and aluminum phosphates. It is this leaching that is at least partly responsible for much of the high grade ore that has been mined for many years. Like any good thing, too much of it is detrimental and this natural highgrading has destroyed hundreds of millions, perhaps even a billion tons of phosphate throughout the upper matrix strata while it was in the process of enriching the underlying matrix.

This leaching effect on the matrix can be traced from north to south by the following chemical changes, a decrease in P₂O₅ of phosphate particles, a decrease in iron and aluminum oxides in the matrix, a general decrease in thickness of leach zone strata, an increase in (CO₂) carbonate content, and an increase in the MgO content (dolomite). Gradual changes in the leach section can be traced from region to region, and it seems likely that the upper Pliocene sea had an average strand line several miles into Northern Hardee County on the east side of the field and the line was farther north in Hillsborough County due to lower structural elevations. This would place the strand line at about the 70-90 foot MSL structural contour. The leach zone is considered to be the Upper Bone Valley Formation.

-8-

Unit "8" consists of grey, tan, and white sands and clayey sands above the leach zone. Some lenses of clay are occasionally present and the unit can show signs of marine borings and leaching.

The unit represents a totally destroyed matrix in some areas and/or a distinct depositional cycle in other areas. Clay lenses in the unit occasionally yield a terrestrial fauna from the middle Pliocene to near recent. The older faunas appear to be remnants of original matrix that was severely leached and the youngest faunas are found under shallow overburden. The general stratigraphy indicates that despite some areas of a deceptive nature, a general transgression and influx of clastics occurred in early to mid-Pleistocene time. This influx probably represents at least one, if not several, of the high sea levels that occurred during the Pleistocene. This is supported by the existence of "sand pockets" cutting through the leach zone and matrix in many of the existing mines.
These sand pockets are discontinuous linear fragments of what must have been active water courses as the sea level fluctuated during the Pleistocene. Virtually all of these sand pockets are barren of fauna and the increased permeability of the sandy material often increases the leaching of the matrix in contact with the sand pocket.

Unit "9" can often be related directly to an altered unit "8" and must be a mid-Pleistocene to recent alteration deposit. The basic ingredients are usually the same or similar but Pleistocene to recent ground water activity has altered the appearance and composition somewhat. The normal alteration is iron cementing in the form of iron silicates or oxides into what is known as hardpan. There is a distinct correlation to the water table and the location of hardpan in many areas. An unknown variable is whether a particular vegetation cover has accentuated the development of hardpan. This strata often consists of tan, iron-stained sands that show definite evidence that the iron stain has progressed downward in the section. Thus, this unit is an equivalent to the "C" horizon in soil stratigraphy. It is not uncommon for a "B" soil horizon of white (sugar sand) to overlie the iron stained material. The "A" horizon is common throughout the field and represents the uppermost strata that includes organic material.

This strata represents water reworking of the matrix in low areas that are now stream beds. Various intertidal to fresh water faunas are present at most locations due to the fluctuating sea levels of the Pliocene and Pleistocene. This unit usually is clay, sand, and muck intermixed with linear pebbly sand beds of reworked lag deposit phosphate. Pliocene faunas can be found but preservation in this type deposit favors the mid-Pleistocene to recent faunas due to the high energy level of the unit. The best known fossil from this unit is the Pleistocene horse *Equus*. A common name for this type of deposition is river pebble phosphate.

Included in this paper is a series of line drawings, Figure II, of the upper molars of the genus listed. It is beyond the capability of a beginner to correctly identify these teeth to genus and species. The paper presented here represents years of specimen collecting in conjunction with several museums professional help. The author recommends that anyone wishing to identify specimens contact the Florida State Museum, Department of Natural Sciences, University of Florida, Gainesville, Florida 32611.
**Parahippus blackbergi**
3/8" X 3/8" X 1/2"

**Merychippus sp.**
Variable Size

**Calippus sp.**
1/2" X 1/2" X 1&1/2"

**Nannippus phlegon**
1&1/2" X 1/2" X 3/4"

**Neohippparion eurystyle**
7/8" X 7/8" X 2"

**Felsinotherium floridanus**
1 & 1/8" X 1" X 1 & 1/2"

**Nannippus ingenuus**
3/4" X 3/4" X 1"

**Equus sp.**
1 & 1/4" X 1 & 1/4" X 3"

**FIGURE II**
ROAD LOG

SOUTHEASTERN GEOLOGICAL SOCIETY FIELD TRIP

ENVIRONMENT OF THE CENTRAL FLORIDA PHOSPHATE DISTRICT

Saturday, December 3, 1977

Mileage

<table>
<thead>
<tr>
<th>Between Points</th>
<th>Cumulative</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>Leave Ramada Inn at 601 East Memorial Blvd., Lakeland, heading east on Memorial Blvd.</td>
</tr>
<tr>
<td>0.7</td>
<td>0.7</td>
<td>Turn right (south) on U. S. 98.</td>
</tr>
<tr>
<td>0.7</td>
<td>1.4</td>
<td>Junction U. S. 92 Bus., continue south on U. S. 98.</td>
</tr>
<tr>
<td>0.4</td>
<td>1.8</td>
<td>Road years left, continue south on U. S. 98.</td>
</tr>
<tr>
<td>2.5</td>
<td>4.3</td>
<td>Turn right, west on S.R. 35A.</td>
</tr>
<tr>
<td>0.6</td>
<td>4.9</td>
<td>Lake Bently on right. Lake Bently and the Sylvester Shores subdivision are on reclaimed land previously mined by W. R. Grace.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Continue west on S.R. 35A</td>
</tr>
<tr>
<td>0.1</td>
<td>5.0</td>
<td>Junction S.R. 37B, turn left (south) onto 37B.</td>
</tr>
<tr>
<td>1.4</td>
<td>6.4</td>
<td>Meadows housing development on right. All of the area was reclaimed before being required by law.</td>
</tr>
<tr>
<td>1.2</td>
<td>7.6</td>
<td>Turn right (west) on Miriam Drive.</td>
</tr>
<tr>
<td>2.0</td>
<td>9.6</td>
<td>Shopping center on right was partially reclaimed by W. R. Grace and completed by the developers.</td>
</tr>
<tr>
<td>0.2</td>
<td>9.8</td>
<td>Turn left on S.R. 37.</td>
</tr>
</tbody>
</table>
# Mileage

<table>
<thead>
<tr>
<th>Between Points</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>11.4</td>
</tr>
<tr>
<td>0.1</td>
<td>11.5</td>
</tr>
<tr>
<td>0.5</td>
<td>12.0</td>
</tr>
<tr>
<td>0.3</td>
<td>12.3</td>
</tr>
<tr>
<td>0.6</td>
<td>12.9</td>
</tr>
<tr>
<td>1.8</td>
<td>14.7</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.4</td>
<td>16.1</td>
</tr>
<tr>
<td>0.6</td>
<td>16.7</td>
</tr>
<tr>
<td>3.7</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Turn left (east) on S.R. 540A.  
Christina Park – park reclamation area on left, lake on right.  
Turn right (south) into Christina development – exclusive home sites – started in the early 70's. Reclamation area by I.M.C.  
Stop sign, turn right (west), continue west to S.R. 37.  
Turn left (south) on S.R. 37.  
Land and lake on left – old reclamation area by W. R. Grace and Company.  
Golf course on right, land reclamation by I.M.C.  
Mulberry City limits, continue south on S.R. 37.  
Turn left (east) on S.R. 60.  
Turn left (north) into W. R. Grace and Company.  

---

### Stop I

Reclamation of mined out areas has been in effect at W. R. Grace since 1948 even though laws governing reclaimed land have only been in force since 1971. A good indication of the efforts in this area by the phosphate industry is the amount of reclamation completed. Between 1961 and 1974, 25,000 acres were reclaimed with 50,000 acres mined.

Ecological considerations are also a major effort in our chemical plant. Continuous monitoring by our environmental staff indicates far better than required federal and state pollution standards.
BONNY LAKE

Coming into the plant area off State Road #60, the dry mill and phosphate rock storage piles will be on your right. Just north of the dry mill is the chemical plant complex. At this complex we produce sulfuric acid and various phosphate products. Most of our sulfuric acid is used internally in the manufacture of phosphoric acid. Other products from this plant are: Hydrofluosilicic Acid, Granular Triple Superphosphate and Granular Diammonium Phosphate.

The next group of buildings to the northwest of the chemical plant is the Bonny Lake washer and float plant. Phosphate matrix slurry is pumped to the washer from 2 draglines located roughly 3 miles west and northwest of here. The 2 draglines are made by Bucyrus Erie:

1 -- 21 cubic yard 770-B
1 -- 42 cubic yard 1350-W

The slurry is screened and washed here. Washer rock products fall into 3 mesh sizes: Coarse +6 mesh, fine -6+14, and classified product -14+20. The finer material is then pumped to the beneficiation plant where a two stage flotation process separates the sands and fine grained phosphate.

Looking to the south from the top of the tailings pile just west of the washer, you will be able to view our current reclamation project. The land just west of the dry mill and north of State Road #60 was mined in 1975 and is already reclaimed.

Moving west down the tailings road, you may see some of the numerous birds which inhabit some of the old pits. Some of the more typical inhabitants include: Egrets, Great Blue Herons, Iron Head Storks and Red-wing Blackbirds. Many of these pits also provide fishing holes.

From the gate entrance off Highway #60, just east of Mulberry, is another active reclamation area. The area northeast of the gate has only been mined since the first part of this year and is nearly completely reclaimed now. The ball field northwest of the gate is also on reclaimed land, as is the property across the street from the dry mill.

Jeff B. Brami
Geologist
FL OWSHEET

OPEN PIT MINING OPERATION

PIPELINE

TO WASTE DISPOSAL & LAND RECLAMATION

SAND & PHOSPHATIC CLAY

BENEFICIATION PLANT

R.R. CARS

WET ROCK STORAGE

CONVEYOR TO NEW WET ROCK GRINDING

CONVEYOR

DRYING & SHIPPING

CONVEYOR

GYPSUM TO WASTE DISPOSAL

CHEMICAL OPERATIONS

AGRICULTURAL CHEMICAL PRODUCTS TO EXPORT & INTERNAL SALES

TO EXPORT & INTERIOR ROCK SALES

Jeff B. Brani
Geologist
W.R. Grace & Co.
AGRICULTURAL CHEMICALS

FLORIDA

JACKSONVILLE

TALLAHASSEE

ORLANDO

HILLSBOROUGH COUNTY

POLK COUNTY

MANATEE COUNTY

NAPLES

MIAMI
### Mileage

<table>
<thead>
<tr>
<th>Between Points</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Leave W. R. Grace and Company, turn right (west) on S.R. 60.</td>
</tr>
<tr>
<td>0.2</td>
<td>Turn left (south) on Bonnie Mine Rd.</td>
</tr>
<tr>
<td>2.1</td>
<td>C. F. Industries on right.</td>
</tr>
<tr>
<td>2.2</td>
<td>Turn right (west) on S.R. 640.</td>
</tr>
<tr>
<td>0.6</td>
<td>Uranium Recovery Plant on right.</td>
</tr>
<tr>
<td>1.5</td>
<td>Junction old S.R. 37, continue west on S.R. 640.</td>
</tr>
<tr>
<td>0.2</td>
<td>Turn left (south) on S.R. 37.</td>
</tr>
<tr>
<td>2.6</td>
<td>I.M.C. Kingsford mine on right.</td>
</tr>
<tr>
<td>1.3</td>
<td>Bradley Junction, turn left (east) at sign to Bone Valley Fossil Museum.</td>
</tr>
<tr>
<td>0.2</td>
<td>Junction old S.R. 37, continue east on old S.R. 37.</td>
</tr>
<tr>
<td>0.3</td>
<td>Year left (north), continue north on old S.R. 37.</td>
</tr>
<tr>
<td>0.5</td>
<td>Railroad crossing.</td>
</tr>
<tr>
<td>-</td>
<td>Turn right (east) on Agricola Rd.</td>
</tr>
<tr>
<td>2.3</td>
<td>Turn right (south) to entrance to W. R. Grace Hookers Prairie Mine.</td>
</tr>
</tbody>
</table>

---

**Stop 2**

Almost 9 miles south of Bonny Lake is the Hookers Prairie Mine. The Hookers tract is a low lying swamp occupying 6,700 acres. Elevations in this area average 120 to 130 feet which is nearly 100 feet below the Bonny Lake area.

This mine came on stream early this year with the largest dragline in Florida, a 65 cubic yard Bucyrus Erie 1370-W. On a 7 day/week schedule, this plant has a total capacity of 2.8 million tons per year.
Hookers Prairie Mine

Cross Section

NE¼, Section 19, T31S, R24E

Surface Elev = 125' MSL

Tailing: Sand Fill (Plan View)

Unit 1: Black mud and gray clayey silt showing interbedded organic mats

Unit 2: Mixed layers of gravel and clayey sand

Unit 3: Grey sandy clay with signs of oxidation

Unit 4: Light gray sand with shell casts, traces of shell casts at lower elevations

Unit 5: Grey-yellowish clay residuum

Unit 6: Grey-yellowish clay residuum

Unit 7: Light gray sand with shell casts, traces of shell casts at lower elevations

Unit 8: Grey clay residuum

Unit 9: Black mud and gray clayey silt showing interbedded organic mats

Earth and yellowish clay residuum

Traces of shell casts at lower elevations exposures

Trace of lean tan and brown phosphate pebbles

Approximate scale:
2" = 100' Horizontal
1/2" = 10' Vertical

Unit 3 shows a strong basal conglomerate and diastem at the lower contact. The upper contact is thin but gradational and conformable. The unit consists of a grey-green sandy clay with a moderate yield of brown phosphate pebbles.

D. C. Crissinger
11-27-77
Hookers Prairie is primarily a small pebble and concentrate deposit which is typical of the southern Florida phosphates.

After visiting the matrix face in the pit, another locality will be available for fossil collecting, time permitting.

Jeff B. Brami
Geologist

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Between Points</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.3</td>
<td>Turn left (south) on old S.R. 37.</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>Continue west from old S.R. 37 to S.R. 37.</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>Turn left (south) on S.R. 37.</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>I.M.C. current reclamation project on right.</td>
</tr>
<tr>
<td></td>
<td>2.4</td>
<td>Brewster Phosphate Haynesworth Mine on right, continue south on S.R. 37.</td>
</tr>
<tr>
<td></td>
<td>3.9</td>
<td>Turn right (west) on S.R. 674.</td>
</tr>
<tr>
<td></td>
<td>1.1</td>
<td>Turn left (south) into Agrico Camp.</td>
</tr>
</tbody>
</table>

Stop 3

Lunch at Agrico Chemical Company's Agrico Camp.

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Between Points</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.1</td>
<td>Turn right (south) on S.R. 37.</td>
</tr>
<tr>
<td></td>
<td>2.6</td>
<td>Turn left (east) into Agrico Ft. Green Phosphate Mine.</td>
</tr>
</tbody>
</table>
Stop 4

FORT GREEN MINE
AGRICHEMICAL COMPANY

Initial planning for Agrico Chemical Company's Fort Green Mine began in the mid-1960's with the purchase of what was then known as the Consolidated Chemical tract, which is roughly the north one-half of the present Fort Green Mine. With the subsequent purchase of the Whidden and Stauffer Chemical tracts, plans were officially approved for construction of Fort Green.

Construction of the primary settling area (Section 21-32-23) began in March 1974. The washer and recovery plant (NE 1/4 of 28-32-23) began construction in March 1974 and January 1975, respectively. The first pebble production from Fort Green came on March 10, 1975, and from March until November of 1975, when the recovery plant was completed, the feed (-14M) was collected in the feed storage area (W 1/4 of 22-32-23).

Three Bucyrus-Erie draglines feed Fort Green, two B-E 1260-W machines with 42 cubic yard buckets and a B-E 1250-W with a 34 cubic yard bucket. Designed capacity of Fort Green will yield between 3.0 and 3.5 million tons annually. At the present time Fort Green is mining in Polk County and with approval of Agrico's DRI, Fort Green can expand into Hardee County.

Raymond T. Middel
Senior Geologist

Edward R. Yopp
Geologist

Agrico Chemical Company
Mining Division

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Between Points</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>11.6</td>
<td>60.9</td>
</tr>
</tbody>
</table>

Leave Agrico Ft. Green Phosphate Mine, turn right (north) on S.R. 37.

Turn right (east) on Jameson Rd.
AGRICHEMICAL COMPANY
FORT GREEN MINE
T32S, R23E

1. Feed (-14M) Storage Area
2. Tail Fill Reclamation
3. Agrico Park
4. Active Mining Area, B-E 1260W
5. Inactive Mining Area

Mined Out Lands
Topsoil
Brown sand with very minor clay, fine to medium grained.

Gray to tan sand - clayey sand with minor hardpan (sandstone pebbles), fine to medium grained, thickens to east.

Gray to cream colored sand - sandy clay, thickens to west, clay contents increase to west; tan sand - clayey sand, fine to medium grained.

Tan sand - clayey sand, fine to medium grained.
Gray, tan, brown, green clayey sand with lean fine black phosphate, host is fine grained, color darkens to east. This zone contains gradational matrix (phosphate ore) contact.
Soft gray, tan, brown sand - clayey sand, fine to medium grained, with minor stringers of sticky tan clay to the west, grading to tan sand - clayey sand on the east with both fine grained black and brown phosphate and black to brown phosphate pebbles.

Bedclay
Hawthorn Formation - yellow, brown, cream limey clay and limestone with lean fine or phosphate.

Sieve Analysis of (-14+150M)  
(1000 grms. sample wet)

<table>
<thead>
<tr>
<th>MESH</th>
<th>WT.(GRMS) DRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>35</td>
<td>86</td>
</tr>
<tr>
<td>48</td>
<td>216</td>
</tr>
<tr>
<td>65</td>
<td>212</td>
</tr>
<tr>
<td>150</td>
<td>274</td>
</tr>
</tbody>
</table>

Total: 818
COMPOSITE OF FOUR HOLES

2' Black topsoil, rich in organic material and sand.

Gray, cream to white sand with minor clay content. Fine grained and spherical.

8' Brown to tan sand to clayey sand. Fine to medium grained. This zone contains 1 to 5 feet of a gradational to distinct matrix (phosphate ore). Contact more distinct to the west and south. Lean fine grained phosphate.

10' Gray sand, sandy clay and clayey sand. Fine grained host with phosphate pebbles (+14M). Black to brown in color, and fine to medium grained phosphate feed; also black to brown in color. Clay content increasing to the west and south.

11.5' Soft white to cream limey clay and clay, lean fine grained phosphate.

6' Green to gray clayey sands with lean to fair fine grained black and brown phosphate. Stiff green clays to the west.

9' Hawthorn formation white to yellow and cream colored limey clays and limestones with lean fine grained phosphate.

Sieve Analysis of (-14+150M)
(1000 grms. sample wet)

<table>
<thead>
<tr>
<th>MESH</th>
<th>WT.(GRMS)DRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>35</td>
<td>134</td>
</tr>
<tr>
<td>48</td>
<td>196</td>
</tr>
<tr>
<td>65</td>
<td>214</td>
</tr>
<tr>
<td>150</td>
<td>268</td>
</tr>
</tbody>
</table>

838
Approximate Scale:
1" = 100' horizontal
1/4" = 10' vertical

Surface clay 13'-14'

8' - Dirty white sand and slightly clayey sand

10' - Bi-sand and clayey sand

15'-20' - Pink shelly limestone diminishing upward to trace levels 20'-30' - Pink shelly limestone

26' - Pink shelly limestone and clayey sand

30' - Irregular bedded sandstones, clay and siltstone beds - Trace greyish limy shales

Silica cemented sandstones - very dense

Date Crossing 27
11/23/77
<table>
<thead>
<tr>
<th>Mileage</th>
<th>Between Points</th>
<th>Cumulative</th>
<th>Directions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>61.4</td>
<td>Turn left (north) on old S.R. 37.</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>62.2</td>
<td>Agrico Chemical on left.</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>62.3</td>
<td>Turn right (northeast) on Pebbledale Rd.</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>62.8</td>
<td>Mined area (pre-1950) unreclaimed.</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>63.2</td>
<td>Electro-Phos Corp. on left.</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>63.6</td>
<td>Mined area (pre-1950), unreclaimed.</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>64.2</td>
<td>Junction Bonnie Mine Rd., continue northeast.</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>64.3</td>
<td>Turn right (east) on S.R. 640.</td>
</tr>
<tr>
<td></td>
<td>2.1</td>
<td>66.4</td>
<td>Farmland Industries - Green Bay Plant on left.</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>67.0</td>
<td>I.M.C. Phosphoria Mine on right.</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>67.9</td>
<td>Reclamation area on left, land and lake, improved pasture.</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>68.1</td>
<td>Turn left (north) on County Road 555.</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>69.6</td>
<td>Reclamation area on right, sand tailings fill, old mine cuts capped with overburden.</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>71.2</td>
<td>Reclamation area on left.</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>72.5</td>
<td>Reclamation area on left used for recreation, ahead to the right is agricultural and industrial sites on reclaimed land.</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>73.1</td>
<td>Turn right (east) on S.R. 60.</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>73.2</td>
<td>Bartow city limits.</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>73.4</td>
<td>Turn left, continue east on S.R. 60.</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>74.3</td>
<td>Turn left on U. S. 98.</td>
</tr>
<tr>
<td>Between Points</td>
<td>Cumulative</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>75.0</td>
<td>Leaving Bartow city limits.</td>
<td></td>
</tr>
<tr>
<td>8.2</td>
<td>83.2</td>
<td>Junction S.R. 35A, continue north-west on U. S. 98.</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>83.7</td>
<td>Lakeland city limits.</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>85.7</td>
<td>Junction U. S. 98 Bus., turn right, continue north on U. S. 98.</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>86.8</td>
<td>Junction U. S. 92/98 (Memorial Blvd.), turn left (west).</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>87.5</td>
<td>Arrive Ramada Inn.</td>
<td></td>
</tr>
</tbody>
</table>
The following publications can be ordered from

Southeastern Geological Society
Post Office Box 1634
Tallahassee, Florida 32302

Add 50 cents per publication ordered to cover handling and mailing charges. Allow reasonable time for processing order. Please enclose payment with order.

**Guidebooks**

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Geology of the Crystalline Rocks and of the Paleozoic Area of Northwest Georgia. 1951.</td>
<td>$3.00</td>
</tr>
<tr>
<td>9</td>
<td>Late Cenozoic Stratigraphy and Sedimentation of Central Florida. 1960.</td>
<td>3.00</td>
</tr>
<tr>
<td>11</td>
<td>Highlights of the Cretaceous and Crystalline Terrains of Georgia. 1965.</td>
<td>2.00</td>
</tr>
<tr>
<td>12</td>
<td>Miocene-Pliocene Series of the Georgia-Florida Area. 1965.</td>
<td>3.00</td>
</tr>
<tr>
<td>13</td>
<td>Miocene-Pliocene Problems of Peninsular Florida. 1967.</td>
<td>1.50</td>
</tr>
<tr>
<td>14</td>
<td>Geology and Geohydrology of the Cross-Florida Barge Canal Area. 1970.</td>
<td>3.00</td>
</tr>
<tr>
<td>15</td>
<td>Geologic Review of Some North Florida Mineral Resources. 1971.</td>
<td>3.00</td>
</tr>
<tr>
<td>16</td>
<td>Space Age Geology - Terrestrial Applications, Techniques and Training. 1972.</td>
<td>3.00</td>
</tr>
<tr>
<td>17</td>
<td>Hydrogeology of West-Central Florida. 1975.</td>
<td>5.00</td>
</tr>
<tr>
<td>18</td>
<td>Mid-Tertiary Carbonates, Citrus, Levy, and Marion Counties, West-Central Florida. 1976.</td>
<td>5.00</td>
</tr>
<tr>
<td>19</td>
<td>Environment of the Central Florida Phosphate District. 1977.</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Prices subject to change without notice.