GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: August 23, 1974

Project Title: Raw Material Sources of Domestic Phosphate
Project No.: E-19-628
Principal Investigator: Dr. John E. Husted
Sponsor: U.S. Bureau of Mines
Agreement Period: From June 29, 1974 Until June 28, 1976 (performance period)
Type Agreement: Contract No. SO144132
Amount: $23,995
Reports Required: Quarterly Technical Letter, Quarterly Financial Letter, Intermediate (if contract is extended), Final Technical

Sponsor Contact Person(s):

R. D. Thomson (COR), Technical Project Officer
Bureau of Mines
Pittsburgh, PA 15213

*Plus 2 months for submission, review, and final submission of final report.

Assigned to: Chemical Engineering

COPIES TO: Principal Investigator
Library
School Director
Rich Electronic Computer Center
Dean of the College
Photographic Laboratory
Director, Research Administration
Project File
Director, Financial Affairs (2)
Security-Reports-Property Office
Patent Coordinator
Other:

RA-3 (6-71)
Project Title: Raw Material Sources of Domestic Phosphate

Effective Termination Date: 7/30/76

Clearance of Accounting Charges: 7/30/76

Grant/Contract Closeout Actions Remaining:

X Final Invoice and Closing Documents
X Final Report of Inventions
X Govt. Property Inventory & Related Certificate
- Classified Material Certificate
- Other

Assigned to: Chemical Engineering (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
Security Coordinator (OCA)
Reports Coordinator (OCA)
Mr. Robert D. Thompson, Chief
Eastern Field Operation Center
U. S. Bureau of Mines
4800 Forbes Street
Pittsburgh, Pennsylvania 15213

Reference: U. S. Bureau of Mines Contract Number 50144132
Georgia Tech Project Number E19-628
Quarterly Technical Letter Number 1
July 1 through September 30, 1974

Dear Mr. Thompson:

In accordance with instructions work on this project was not to start
until S0122100 was completed. Present planning is to start work during
the third quarter of the Project, or January-March, 1975.

Sincerely yours,

(John E. Husted,
Project Director

JEH:hdr
Mr. R. D. Thomson  
(COR) Technical Project Officer  
U.S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213  

References:  U.S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Technical Letters 2 and 3  
October 1, 1974 through March 31, 1975  

Dear Mr. Thomson:  

As noted in our Technical Letter, Number 1, of October 14, 1974,  
no work was contemplated or done during the second quarter.  Beginning  
in the third quarter a student assistant was added to the project and  
work on literature references, names and locations of companies engaged  
in phosphate mining, etc. was begun. Approximately one week per month  
was devoted to the Project.  

Sincerely yours,  

John E. Husted  
Project Director
Mr. R. D. Thomson  
(COR) Technical Project Officer  
U. S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213

Reference: U.S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Technical Letter Number 4  
April 1, 1975, through June 30, 1975

Dear Mr. Thomas:

Technical work for the subject period was devoted for the most part to obtaining information for the work sheets, particularly as related to non-operative data such as locations, geologic descriptions, and background for reserve estimates. A student was used for the entire quarter, to the extent he had time available. A trip to Washington was made for conference purposes.

All companies in Tennessee, North Carolina, and Florida, as found in the literature, had work sheets prepared to the extent of available information. This should facilitate and expedite the plant visits planned as a follow up to the literature work.

Sincerely yours,

John E. Husted  
Project Director
Mr. R. D. Thomson  
(COR) Technical Project Director  
U.S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213

Reference: U.S. Bureau of Mines Contract Number 50144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Technical Letter Number 5  
July 1, 1975 through September 30, 1975

Dear Mr. Thomson:

During the subject period a total of 0.69 man months effort was made. No work was done during July and only one day in September. The bulk of the work was in August and consisted of a conference in Atlanta, Georgia, with Mr. Lyday of your staff, a visit to the Tennessee phosphate area near Columbia, Tennessee, and calculating and assembling data on the work sheets for Tennessee.

Data was obtained on twelve properties owned or operated by four companies in five counties. When completed, the Tennessee work will be forwarded. Work effort for the sixth quarter (October-December 1975) is scheduled as a total of seven work days for the quarter because of my teaching load.

The seven days will be on the Tennessee work sheets with a possible trip to the North Carolina phosphates during December.

Sincerely yours,

John E. Husted  
Project Director
Mr. R. D. Thomson  
(COR) Technical Project Director  
U.S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213

Reference: U.S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Technical Letter Number 6  
October 1, 1975 through December 31, 1975

Dear Mr. Thomson:

During the subject period a total of seven days were worked of which four days, including travel time, were devoted to securing information on North Carolina phosphates.

Immediately prior to the visit to North Carolina there had been adverse newspaper articles regarding the attitudes of members of the Aurora, N.C. community area to phosphate mining. This resulted in a marked "freeze" on information that the companies would release. Despite this, most required information was obtained. The exception was current cost information as well as exact amounts and locations of owned or leased land. For competitive reasons this information would probably not be released anyway. All in all the North Carolina phosphate area represents a remarkable concentration of phosphate reserves.

The remaining three days were spent on the Tennessee work sheets. The scattered nature of the deposits and lack of precise information requires considerable time in working up reserve information for the Tennesse phosphate deposits.

Sincerely yours,

John E. Husted  
Project Director
Mr. R. D. Thomson  
(COR) Technical Project Director  
U. S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213

Reference: U. S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Technical Letter Number 7  
January 1, 1976 through March 31, 1976

Dear Mr. Thomson:

During the subject period a total of 0.36 man months effort was made which was evenly divided through the quarter. At the suggestion of Mr. Lyday the work was spent on the North Carolina data. A completed group of Worksheets on Texasgulf was forwarded at the end of the quarter for corrections and suggestions. Sets of worksheets for each of the three companies in North Carolina are essentially complete and will be forwarded as soon as reserve and financial estimates can be checked with the company concerned.

Work effort during the remaining quarter will be increased to approximately 66 percent per month as I will not teach the Spring Quarter.

Sincerely,

John E. Husted  
Project Director
Mr. Robert D. Thompson, Chief
Eastern Field Operations Center
U. S. Bureau of Mines
4800 Forbes Street
Pittsburgh, Pennsylvania 15213

REFERENCE: U. S. Bureau of Mines Contract Number 50144132
Georgia Tech Project Number E-19-628
Quarterly Financial Letter Number 1
July 1 through September 30, 1974

Dear Mr. Thompson:

In accordance with Item 2.3 of our Contract we wish to report that there were no expenditures during the subject period. As will be noted on the attached graph, work and expenditures are being scheduled to start January 1975.

Sincerely,

John E. Husted
Project Director
Mr. R. D. Thomson  
(COR) Technical Project Officer  
U. S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213  

Reference: U.S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Financial Letter Numbers 2 and 3  
October 1, 1974 through March 31, 1975  

Dear Mr. Thomson:  

No funds were expended through the second quarter as projected in our letter of October 14, 1974. The expenditures below reflect expenditures in the third quarter, beginning January 1, 1975. My time during the third quarter was budgeted at 25 per cent. In addition we used a student assistant.  

<table>
<thead>
<tr>
<th>Item</th>
<th>Third Quarter</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
<td>$1,550.78</td>
<td>$1,550.78</td>
</tr>
<tr>
<td>Retirement (8.77%)</td>
<td>133.83</td>
<td>133.83</td>
</tr>
<tr>
<td>Materials &amp; Supplies</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Travel</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Overhead (65%)</td>
<td>1,008.01</td>
<td>1,008.01</td>
</tr>
<tr>
<td></td>
<td>$2,692.62</td>
<td>$2,692.62</td>
</tr>
</tbody>
</table>

Sincerely yours,  

John E. Husted  
Project Director
1st Quarter 1974
Contract Number: S0144132

2nd Quarter 1974
Project Number E-19-628

3rd Quarter 1974

4th Quarter 1975

5th Quarter

Projected Total Expenditure

Total Expenditures To Date

Projected Total Personal Services
Personal Services Expended

Projected Total Travel
Travel Expended
Mr. R. D. Thomson  
(COR) Technical Project Officer  
U.S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213  

Reference: U.S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Financial Letter Number 4  
April 1, 1975, through June 30, 1975  

Dear Mr. Thomson:  

In accordance with Item 2.3 of our contract the following financial statement and attached graph are submitted.

<table>
<thead>
<tr>
<th>Item</th>
<th>Fourth Quarter</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Services</td>
<td>$2983.49</td>
<td>$4,534.27</td>
</tr>
<tr>
<td>Retirement (8.77%)</td>
<td>252.14</td>
<td>385.98</td>
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<tr>
<td>Materials and Supplies</td>
<td>46.40</td>
<td>46.40</td>
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<tr>
<td>Travel</td>
<td>75.55</td>
<td>75.55</td>
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<tr>
<td>Overhead (65%)</td>
<td>1939.27</td>
<td>2,947.27</td>
</tr>
</tbody>
</table>

$5296.85 $7,989.47

The lateness of this report was due to several factors that will be explained in a separate letter.

Sincerely yours,

John E. Husted  
Project Director
Mr. R. D. Thomson  
(COR) Technical Project Officer  
U.S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213  

Reference: U.S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Financial Letter Number 5  
July 1, 1975 through September 30, 1975  

Dear Mr. Thomson:  

In accordance with Item 2.3 of our Contract the following financial statement and attached graph are submitted. The fringe benefit overhead rates reflect Defense Contract Audit Agency's changes effective July 1, 1975.

<table>
<thead>
<tr>
<th>Item</th>
<th>Fifth Quarter</th>
<th>Cumulative</th>
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</thead>
<tbody>
<tr>
<td>Personal Services</td>
<td>$1,322.50</td>
<td>$5,856.77</td>
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<tr>
<td>Fringe Benefits (8.936%)</td>
<td>118.18</td>
<td>504.16</td>
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<tr>
<td>Materials and Supplies</td>
<td>9.50</td>
<td>55.90</td>
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<tr>
<td>Travel</td>
<td>162.84</td>
<td>238.39</td>
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<tr>
<td>Overhead (68%)</td>
<td>899.30</td>
<td>3,846.57</td>
</tr>
<tr>
<td>Total</td>
<td>$2,512.32</td>
<td>$10,501.79</td>
</tr>
</tbody>
</table>

Sincerely yours,  

\(\text{John E. Husted}\)  
Project Director
April 16, 1976

Mr. R. D. Thomson  
(COR) Technical Project Officer  
U. S. Bureau of Mines  
4800 Forbes Street  
Pittsburgh, Pennsylvania 15213

Reference: U. S. Bureau of Mines Contract Number S0144132  
Georgia Institute of Technology Project Number E-19-628  
Quarterly Financial Letter Number 7  
January 1, 1976 through March 31, 1976

Dear Mr. Thomson:

In accordance with Item 2.3 of our Contract, the following financial statement and attached graph are submitted. The cumulative sums for Personal Services, Fringe Benefits, and Overhead reflect a University System of Georgia change in salary rates retroactive to September 1, 1975, in accordance with a decision of the State of Georgia Supreme Court. The net addition for Sept. 1, 1975, through December 31, 1975, was $166.85

<table>
<thead>
<tr>
<th>Item</th>
<th>Seventh Quarter</th>
<th>Cumulative</th>
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<tbody>
<tr>
<td>Personal Services</td>
<td>$ 772.80</td>
<td>$ 7,413.81</td>
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<tr>
<td>Fringe Benefits (8.936%)</td>
<td>69.06</td>
<td>643.30</td>
</tr>
<tr>
<td>Materials and Supplies</td>
<td>3.86</td>
<td>71.95</td>
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<tr>
<td>Travel</td>
<td>--</td>
<td>516.79</td>
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<tr>
<td>Overhead (68%)</td>
<td>525.50</td>
<td>4,905.35</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$1,371.22</strong></td>
<td><strong>$13,551.20</strong></td>
</tr>
</tbody>
</table>

Sincerely yours,

John E. Rusted  
Project Director
FINAL REPORT

U. S. Bureau of Mines
Contract S0144132

Phosphates of North Carolina and Tennessee

by

John E. Husted

July, 1976

School of Chemical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332
INTRODUCTION

The subject study, under U.S. Bureau of Mines Contract Number S0144132, was directed toward completion of a materials availability study, under the Bureau's MAS program, of the phosphate industry in North Carolina and Tennessee. The investigator was Dr. John E. Husted of the Georgia Institute of Technology, Atlanta, Georgia. The prescribed methodology was to use the MAS work sheets and to complete information to the extent information was available from industry and literature.

Industry information was proprietary and was generally difficult and in some instances impossible to obtain. Broad parameters, by and large, were furnished such as total acres in say the western half of a quadrangle of Tennessee. Specific information was not furnished by industry. The author's costs estimates were given to industry for confirmation or rebuttal. In general the information was confirmed, excepting instances where industry refused to comment either for or against. In Tennessee some specific tract or site information was obtained from the State of Tennessee.

The report embraces two distinctly different areas. The two areas are different from each other in geography, geology, mining history, mining methods, beneficiation, environmental outlook and sensitivity, and outlook for the future.

One area, the Pamlico River area of North Carolina, is in a Coastal area, underlain by a large continuous bed, generally uniform in grade, of phosphorite, and whose products are directed toward the phosphate fertilizer industry.
Further, the North Carolina deposit has not yet reached its potential and has production outlook for 50 to 100 years. In general, data is better for this area and the scope can embrace essentially the full range of the MAS work sheets.

The other area, the four County area, more or less centered in Columbia, Tennessee, is in the interior area of south central Tennessee. The phosphorite is currently found principally in three phosphate limestone formations, two of which are usually combined as one. Bedding is near horizontal and is extensively cut by erosion. This resulted in a large number of disconnected deposits following the contour of the land at predictable elevations. The mineable phosphorite is in the residual weathered areas of the limestones and not necessarily of uniform grade. The products of the operation are directed toward the chemical industry. The area has been mined for eighty years and is near the end of its history. In many instances only locational data was available with other information taken from regional data or calculated on an estimated factor basis.

Figure 1 is a general location map of the North Carolina area and Figure 2 is a general location map for Tennessee.

DEPOSITS - NORTH CAROLINA
History

The Beaufort phosphate deposit of North Carolina was first discovered in 1951, north of the Pamlico River. The original discovery was in an area where the phosphorite was too deep and too thin to be recovered economically. In 1956 the phosphorite south of the Pamlico River was discovered in the course of ground water investigations by the U.S. Geological Survey. In 1958 the Texas Gulf Corp. began exploration and acquisition of reserves and announced on
Location Map for Beaufort County, North Carolina Phosphates

FMC: FMC Corp.
NCP: North Carolina Phosphate Corporation
TG: Texasgulf, Inc.

Scale: 1/250,000
Location Map for Tennessee Phosphates

H: Hooker Chem. & Plastics Corp.
M: Monsanto Ind. Chemical Co.
S: Stauffer Chem. Corp.
W: M. C. West, Inc.

★ Location of Electric Furnaces
● Location of Tipple
□ Location of Washing Plant other than at Furnace Site.
April 2, 1962 its intention to proceed with development, mining, and product production. Mining began April 1, 1966 with drying, calcining, and fertilizer facilities completed by November 1966.

The design capacity of the operation was 3 million short tons (2.72 million metric tons) of concentrate per year containing 33 percent \( \text{P}_2\text{O}_5 \) after calcination. Announced expansion will raise capacity to 5 million short tons (4.5 million metric tons) by 1979-1980.

The North Carolina Phosphate Corporation plans a 4 million short ton (3.6 million metric tons) capacity plant in the same area. Mining development and plant construction have started.

The FMC owns property north of the Pamlico River and have secured patents on a sub-surface hydraulic mining and lifting method to exploit the phosphorite of that area. There are no announced plans for an operation.

**Ore and Characteristics**

The Beaufort phosphorite underlies over 50,000 acres (20,235 ha) in an area centered under the Pamlico River and extending north and south of the river. The phosphorite is part of the Pungo River formation which pinches out westward and dips 5 to 10 feet per mile (1 to 1.9 meters per kilometers) and thickens to the east. Thickness is from 0 feet in the west to 120 feet (36 meters) in eastern Beaufort County. In the mining area south of the Pamlico River the phosphorite is from 70 feet (21 m) to 105 feet (32 m) deep and approximately 40 feet (12 m) thick. The ore mineral is francolite and the ore averages 14 percent \( \text{P}_2\text{O}_5 \). The concentrated francolite averages 30.66 percent \( \text{P}_2\text{O}_5 \) before calcination and 33 percent \( \text{P}_2\text{O}_5 \) after calcination. The phosphorite is an unconsolidated uniform sized sand of Middle Miocene age. The overburden (Yorktown formation) is also unconsolidated. The Pungo River Formation overlies unconformably the Castle
Haynes limestone which is a major aquifer for the artesian water of the area. The uncovering of this limestone in mining and the repressuring of the aquifer has been a major environmental concern. Agreement has been reached by the environmental authorities and industry as to proper procedures to protect the aquifer.

**Mining**

The upper 30 feet (9 m) of overburden is removed by 19 cu. yd. dragline bucket attached to 175 foot (53 m) boom. A 72 cu. yd. (55 cu. m) dragline bucket attached to a 300 foot (91 m) boom removes the remaining overburden and mines the 40 feet (12 m) of ore. Cuts are 150 feet (46 m) wide by 2100 feet (640 m) long. Ore is slurried from a stockpile and transported to the plant by an 18 inch pipeline. Annual mining capacity was designed for 765 million short tons (694 million metric tons) per year. Restoration of land is required by law.

**Beneficiation**

The slurried ore from the stockpile is scalped with 2 inches and over sizes discarded. Two inch by four mesh material is log washed to break up mud balls. Minus 14 mesh is sent through processing while plus 14 mesh material is discarded. The minus 14 mesh material is deslimed in wet cyclones and sent to a fatty acid flotation section, scrubbed and sent to an amine flotation section. The fatty acid floatation product averages 28 percent $P_2O_5$ (62 BPL) and the amine flotation product averages 30.66 percent $P_2O_5$ (67 BPL). The amine flotation product is dried and then calcined in rotary kilns at a temperatures between 700°C and 815°C. The calcined product has an average of 33 percent $P_2O_5$ (72 BPL). The calcined product is stored in 2000 short tons (1815 metric tons) storage silos. From the storage silos the concentrate may be moved on-site to the
fertilizer plants or transported by barge through the intercostal waterway to Morehead City, a distance of 93 km. Here the concentrate may be either transferred to ocean transport or stored for further shipment by air or water.

Reserves and Grades

The Beaufort phosphorite is of near uniform grade and size with an average of approximately 13.5 to 14 percent $P_2O_5$. Tonnage has been variously estimated from 1.5 to 10 billion short tons (1.36 to 9 billion metric tons) of ore. Some of the discrepancy is between known recoverable ore (south of the Pamlico River) and phosphorite that may be too deep to recover economically by currently used methods, which could increase acreage considered. Some of the discrepancy is on estimated thickness as an average for the whole area. On the whole an excess of 3 billion metric tons would appear reasonable.

Future of the Deposit

If one uses the approximately 21 million metric tons of mined ore per year on completion of the increase of capacity at the Texasgulf facility and the addition of North Carolina Phosphates Corporation's annual capacity, then 1.36 billion tons would last 64 years and 3 billion tons would last 142 years. Certainly, one should expect in excess of 100 years supply of ore at 1980 capacities of present and projected plants.

Should new mining techniques such as FMC's, prove technically feasible and economically viable, then either higher capacity or longer life can be envisioned.
DEPOSITS - TENNESSEE

History

Blue phosphate was discovered in Tennessee in December, 1893. On September 23, 1896 the Tennessee Phosphate Company made their first shipment of phosphate from the Mount Pleasant area. Production in 1896 for Tennessee was 26,400 metric tons with production of 108,717 metric tons in 1897. Production moved slowly upward and was reported by Smith and Whitlatch (1940) as 545,680 metric tons in 1937 from Mount Pleasant district with a total of 13,746,478 metric tons from Mount Pleasant district alone from 1896 through 1937. Total production of phosphate rock for Tennessee through 1975 was 89,895,000 metric tons.

Vigorous production has taken place over the years and has included the present production of Giles, Hickman, Maury, and Williamson counties. Until 1935 production was directed toward utilization of relatively high grade phosphorite, containing values of 30 percent $P_2O_5$, for use as fertilizer.

Electric reduction furnaces, using TVA low-cost electric power, were introduced in 1935. These furnaces could utilize lower grade phosphorites and hence enlarge the useable reserves. Present estimates are that the minimum grade phosphorite for furnaces is on an order of 17 percent $P_2O_5$. Present production is using an average grade of 20 percent $P_2O_5$ or slightly less.

There are three companies operating electric furnaces for reduction of phosphorite to elemental phosphorus. These are all located in Maury County, Tenn. The TVA did operate furnaces through February 1976, but have now discontinued operation. TVA furnaces were at Muscle Shoals, Alabama.

TVA sintered the whole matrix, without washing, with the sintered product being used as furnace feed. The TVA phosphorus was used in making super phosphate fertilizers.
The three companies operating furnaces in Tennessee use a washed matrix for their feed and the phosphorus product is used for various phosphorus chemicals and not for fertilizer.

Monsanto is the oldest furnace operator in the area and has a rated annual capacity of 135,000 short tons (122,470 mt) of phosphorus. They began furnace operation in 1935. They had brought out properties of the old Swann Chemical Co.

The Stouffer Chemical Co. purchased the old Victor Chemical Company in 1959. They have a rated annual furnace capacity of 45,000 st (40,823 mt) of phosphorus.

The Hooker Chemical Co. merged with the Shea Chemical Company in 1958. Shea's first furnace was started in 1953. In 1968 the Occidental Petroleum Corp. purchased the Hooker Chemical Corp., with a name change to Hooker Chemical and Plastics Corp. in the early 1970's. Their rated annual capacity is 57,000 st (51,710 mt) of phosphorus.

Current wet-process phosphate fertilizer production requires a higher grade phosphate ore than does an electric furnace operation. The cost of electric power is a crucial factor in producing fertilizer by use of an electric furnace as 6Kwh are used for each pound of phosphorus. Hence, the depletion of phosphorite of sufficient high grade for a wet process and the escalation of electric power rates has currently eliminated the use of Tennessee phosphates from use as sources of fertilizer. Current uses are solely for phosphorus and phosphorus chemicals.

General Geology

The following is quoted from Smith and Whitlatch (1940): "The rocks of the Central Basin and the adjoining Highland Rim are all of sedimentary origin."
Those exposed in the Central Basin are predominantly limestones of Ordovician age, overlain at places on the west side of the Basin by Silurian limestones and shales. Those exposed in the adjoining parts of the Highland Rim and on the isolated outliers of the Rim within the Central Basin are shales, cherts, and impure limestones of Mississippian age. The relative position of these formations and their relation to the general stratigraphic record are shown in the correlation table.

The formations of the area are near horizontal, and a slight south dip away from the Nashville Dome. Dips are in general less than a degree, hence outcrops follow the contour of the land. The land surface has been dissected by erosional features such as valleys with a resulting somewhat "rolling" topography. Phosphorite is derived from weathering of phosphatic limestones, which as a result of the topography occur in discontinuous bodies over a wide area.

Gentle structural influences have affected the area since the Ordovician, with lifting traceable into Pleistocene and Holocene time.

**Ore and Characteristics**

The following is quoted from Smith and Whitlatch (1940): "The brown rock phosphate deposits of Tennessee are derived chiefly from the Bigby, Cannon, and Leipers formations and, to a lesser extent, from the Hermitage formation. They are the product of residual weathering of the phosphatic limestones of these formations.

"Character of Phosphate. -- The terms "phosphate," "rock phosphate," or even "rock" are used in the brown phosphate districts to include both the coherent plates of calcium phosphate, called "lump rock," and the relatively abundant quantities of loose rounded grains of the same material called "phosphate sand,"
<table>
<thead>
<tr>
<th>Geological Time Scale for Central North America</th>
<th>Units Recognized in This Volume</th>
<th>Membrane Lithologic Equivalents in the Cockrill Quadrangle 1941</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MISSISSIPPIAN</strong></td>
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<td></td>
</tr>
<tr>
<td>Osage</td>
<td>Ft. Payne formation</td>
<td>Tullahoma formation</td>
</tr>
<tr>
<td>Evian</td>
<td>New Providence shale</td>
<td></td>
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<tr>
<td>Mississippian</td>
<td>Ridge Top shale</td>
<td></td>
</tr>
<tr>
<td>Chattanooga</td>
<td>Maury green shale</td>
<td></td>
</tr>
<tr>
<td>CONODIOMORPHIC</td>
<td>Chattanooga shale (upper)</td>
<td>Chattanooga formation</td>
</tr>
<tr>
<td>Ebion</td>
<td></td>
<td>(Absent in Central Basin)</td>
</tr>
<tr>
<td>Utterian</td>
<td></td>
<td>(If present, are represented in the phosphatic beds at the base of the Chattanooga formation)</td>
</tr>
<tr>
<td>Oxiskanian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helmberian</td>
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<td><strong>CAYUGAN Series</strong></td>
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<td><strong>TRIASSIC</strong></td>
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<td>Stones River</td>
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<td>Buffalo River series</td>
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(Adapted from Tenn. Div. Geology Bull. 38, Fig. 4)

**Figure 2.** Correlation table of a part of the geologic formations of Middle Tennessee, including those related to the phosphate deposits of that area.

that are always found associated with the lump rock. More and less clay is always associated with the phosphate sand, and a mixture of these two materials is locally called "muck" or "matrix." Some deposits are largely muck and contain little or no lump rock. The usage of these terms is so common in the brown-rock phosphate industry of Tennessee that they will be retained in this report."

"The term "brown phosphate" is applied to all phosphate derived from the weathering of phosphatic Ordovician limestones, regardless of its true color, which may range from white to a very dark brown. The lump rock may vary in texture from a soft chalky mass, through a porous loosely coherent rock, to a hard tough rock that ranges from dense to a very porous or "honeycomb" texture.

"The typical brown lump-rock phosphate is a loosely coherent, porous, rusty-brown rock, usually in loose plates that rest on one another or on thin layers of muck. The lump phosphate from the Bigby, Cannon, and Leipers formations usually cannot be distinguished lithologically, although those of the last two are commonly coarser-grained and more porous than that of the Bigby and, in places, contain the impressions of fossils, such as brachiopods, that were in the original limestone. The Bigby lump phosphate rarely ever contains any trace of large fossils. Casts or internal molds of Cyclora, the tiny coiled embryo of numerous species of gastropods, are common in all the brown phosphates."

As mentioned under General Geology, the ore bodies are discontinuous and scattered over a wide area.

**Mining and Beneficiation**

Mining is openpit by dragline, shovel, and scrapers. Equipment is usually sized on the basis of a million short tons per year production and is
moved by low-boy trailers from one location to another. Equipment life is generally considered to be 20 years with good maintenance. A 260 work day, one shift, is used. The State of Tennessee has well enforced land restoration laws.

The attached diagram from U. S. Bureau of Mines Information Cir. 7814 (1958) is still valid with the exception that a hydro-cyclone is used instead of a hydro-separator for benefication of raw phosphorite.

Following the above, the concentrate is nodulized and sintered. The nodules are then fed to a reduction furnace when elemented phosphorus produced.

**Reserves and Grades**

With the exception of some very small and isolated reserves that may contain as much as 25 percent $P_2O_5$, the remaining reserves are 20 percent $P_2O_5$ and less. At present, 17 percent $P_2O_5$ is considered the minimum acceptable grade for furnace utilization. Present operations will average 19 ± 1 percent $P_2O_5$, hence under present technology and economics the reserves of ore appear to be near depletion. Lower energy costs or new technology could enlarge the reserves if they permitted utilization of lower grades. On the other hand, further escalation of energy costs could result in shut down of operations if the market would not bear the increased costs of production.

Considering the widely scattered nature of the phosphate reserves remaining in the area, reliable quantitative data is hard to obtain. Total reserves of at least 25,000,000 metric tons with a minimum of 17 percent $P_2O_5$ are estimated to remain in the area.

**Future of the Deposit**

Based on present technology and economics the expected life of the area is generally set at about 10 years minimum.
Figure 7. - Flowsheet of plant for washing Tennessee brown-rock phosphate. 1976 Flowsheet same as above EXCEPT wet cyclones are used instead of hydro-separators.

SUMMARY

The Beaufort County, North Carolina phosphorite deposit is found almost entirely within the county. The deposit, underlies an area in excess of 50,000 acres (20,234 ha), as a near continuous ore body containing in excess of three billion \(3 \times 10^9\) metric tons of phosphorite containing an average of approximately fourteen percent \(P_2O_5\). All present production is for fertilizer.

The ore body, based on projected plant capacities by 1980, should have an expected life of 100 ± 20 years.

The middle Tennessee deposits, for which there is an expectancy of being mined, underlie the following four counties: Giles, Hickman, Maury, and Williamson. The deposits for the most part are found in the Bigby-Cannon formations, with some phosphate in the western area in the Leipers formation. Deposits are scattered and disconnected. The better grades of phosphorite have essentially been depleted. The remaining phosphorite is nearing the minimum grade for electric furnace feed, which is presently set at about 17 percent \(P_2O_5\). Very little phosphorite, if any, remains that can be economically mined and beneficiated to acceptable fertilizer grade phosphates. Despite a higher average grade of remaining phosphorite, the Tennessee phosphorite does not beneficiate as readily and as economically as the North Carolina phosphorite and hence is not currently competitive for fertilizer production. Reserves for the four county area of Tennessee are estimated as in excess of 25 million metric tons of phosphorite containing a minimum of seventeen percent \(P_2O_5\). Life of the deposits is estimated as in excess of 10 years, but probably not as much as 15 years.
SELECTED REFERENCES