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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  
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## 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.

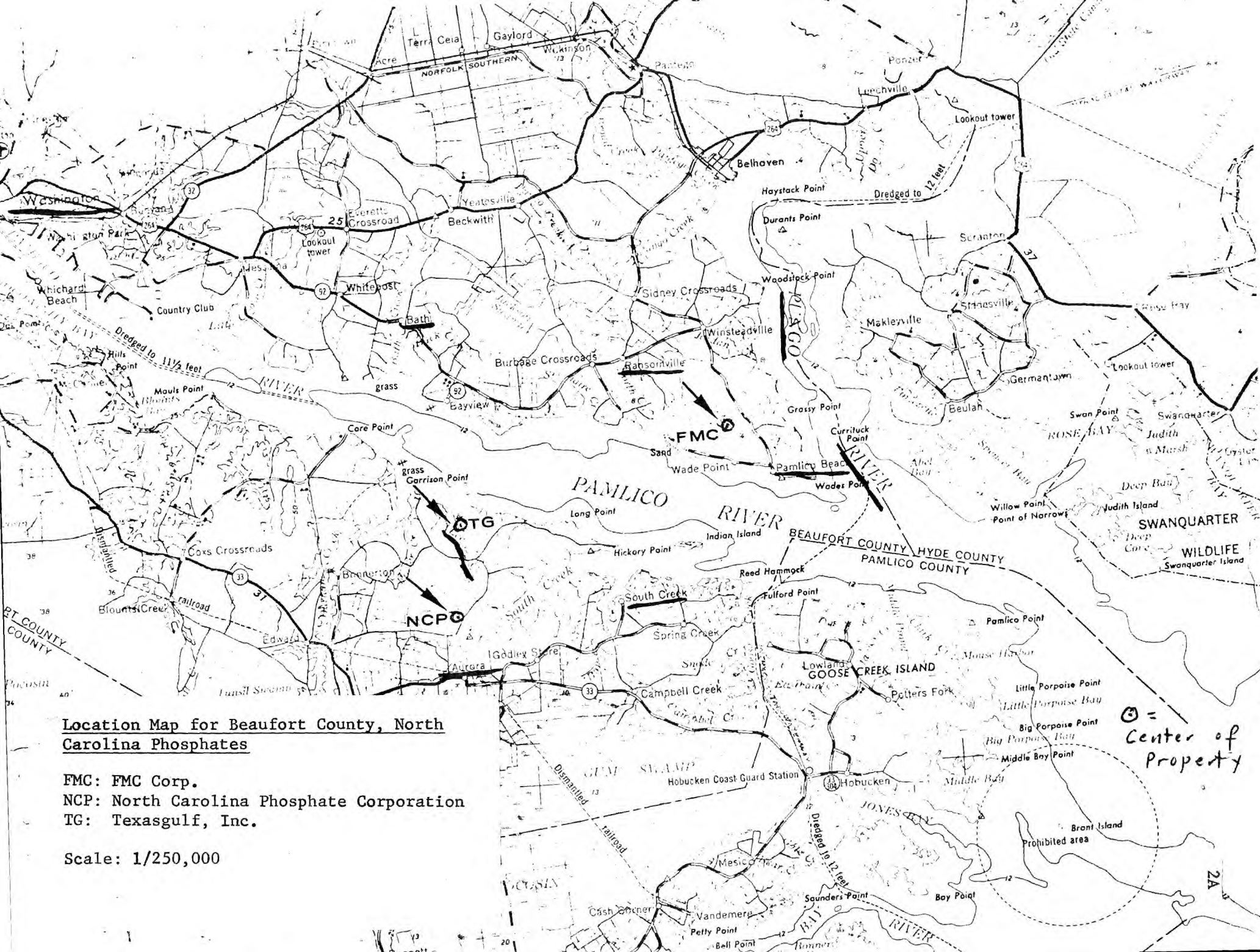
The other area, the four County area, more or less centered in Columbia, Tennessee, is in the interior area of south central Tennessee. The phosphorite is currently found principally in three phosphate limestone formations, two of which are usually combined as one. Bedding is near horizontal and is extensively 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

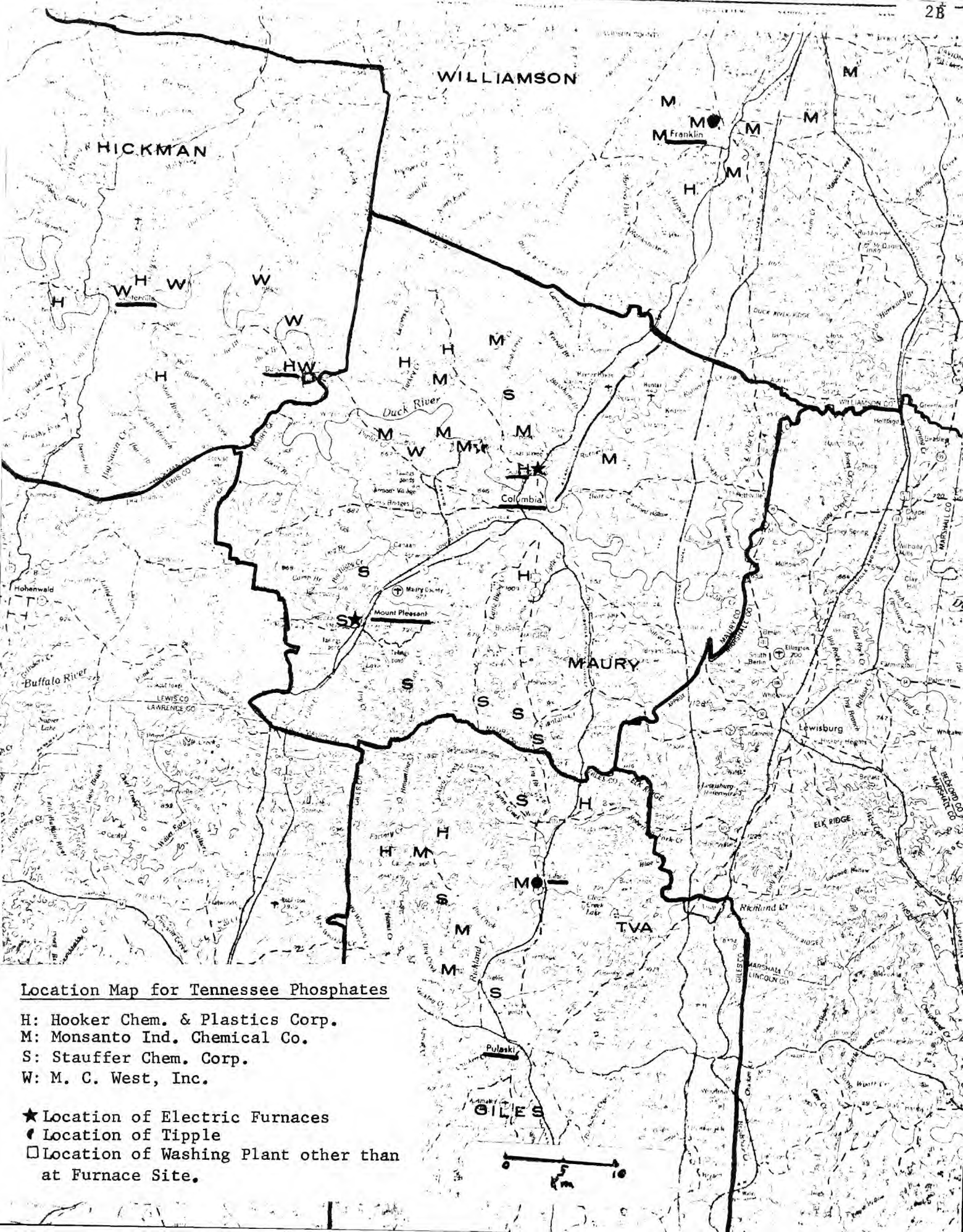
FMC: FMC Corp.

NCP: North Carolina Phosphate Corporation

TG: Texasgulf, Inc.

Scale: 1/250,000





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  $P_2O_5$  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  $P_2O_5$ . The concentrated francolite averages 30.66 percent  $P_2O_5$  before calcination and 33 percent  $P_2O_5$  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 flotation 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  $700^{\circ}C$  and  $815^{\circ}C$ . 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,"



# STRATIGRAPHY CORRELATION TABLE

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GENERALIZED TIME SCALE FOR CENTRAL NORTH AMERICA		UNITS RECOGNIZED IN THIS VOLUME	MAPABLE LITHOLOGIC EQUIVALENTS IN THE COLUMBIA QUADRANGLE 1903
MISSISSIPPIAN	Osagian { Keokuk Burlington	Ft. Payne formation	Tullahoma formation
		New Providence shale	
	Kinderhookian	"Ridgetop shale"	
		Maury green shale	
DEVONIAN	Chattanooga	Chattanooga shale (upper)	Chattanooga formation
	Chemung	Chattanooga shale (lower)	
	Senecan (Portage, Genesee)	Hardin sandstone	
	Erian (Hamilton)	(Absent in Central Basin)	
	Ulsterian (Onondaga)	Jeffersonville limestone	(If present, are represented in the phosphatic beds at the base of the Chattanooga formation)
	Oriskanian	(Absent in Central Basin)	
	Helderbergian	(Absent in Central Basin)	(Wanting)
	Cayuga Series	(Absent)	
SILURIAN	Niagara	Lotelville formation	
		Lego limestone	
		Waldron formation	
		Laurel limestone	
	Clinton	Osgood limestone	(Wanting)
	Medina	Alexandrian	Brassfield limestone
		Richmond	Fernvale formation
	Cincinnati	Leipers formation	Leipers formation
		Eden	(Wanting)
ORDOVICIAN	Mohawkian	Catheys formation	Catheys limestone
		Cannon limestone	Bigby limestone
		Bigby limestone	
		Hermitage formation	Hermitage formation
	Black River	Tyrone limestone	(Wanting)
	Blount { Absent in Central Basin	Carters limestone	Carters limestone
	Chazy	Lebanon limestone	Lebanon limestone
		Ridley limestone	(Not exposed)
		Pierce formation	
		Murfreesboro limestone	
	Buffalo River series		

(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.

From: Smith, R. W., and Whitlatch, G. I., 1940, "The Phosphate Resources of Tennessee," Bul. 48, Div. Geol., Tenn. Dept. Conservation, p.17.

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 beneficiation 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  $19 \pm 1$  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.

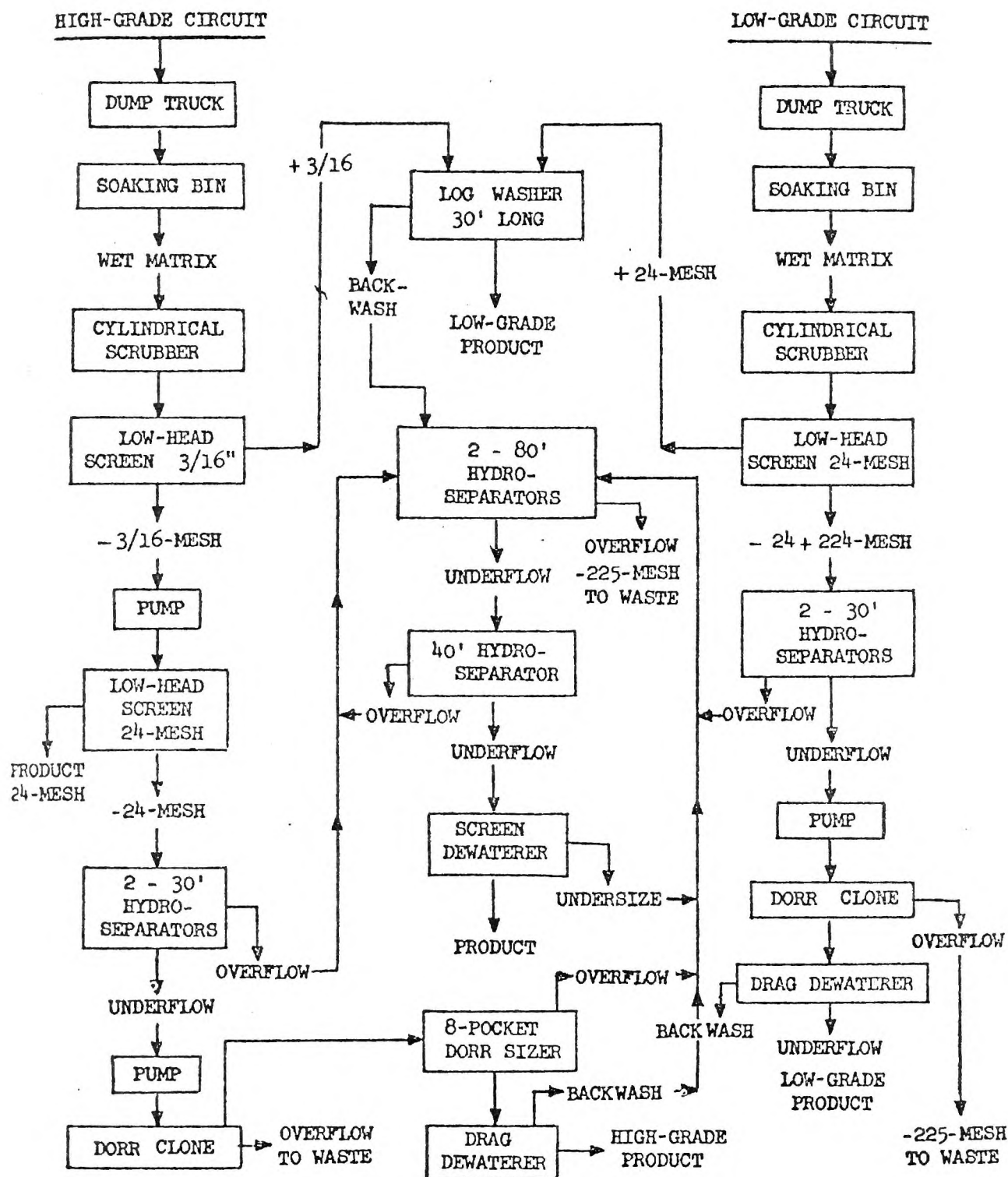


Figure 7. - Flowsheet of plant for washing Tennessee brown-rock phosphate. 1976 Flowsheet same as above EXCEPT wet cyclones are used instead of hydro-separators.



### 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  $100 \pm 20$  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

1. Anonymous, 1969: Another P & Q On the Spot Report: Pit and Quarry, Jan., p. 125-138.
2. Anonymous, 1975: Chemical Profile: 207(12) 9.
3. Anonymous, 1975: Small Carolina Town Fighting for its Life: The Atlanta Journal, p. 21D.
4. Anonymous, undated: The Lee Creek Phosphate Operations: Texasgulf, 20 p.
5. Anonymous, undated: Texasgulf Phosphate: Texasgulf, 17 p.
6. Caldwell, A. B., 1968: Lee Creek Open-Pit Mine and Fertilizer Plants: E and MJ; Vol. 169, Pt. 1, p. 59-83.
7. Emigh, G. D., 1975: Phosphate Rock: Industrial Minerals and Rocks, 4th Ed., p. 935-962.
8. Hignett, T. P., 1967: Can Electric Furnace Phosphoric Acid Compete with Wet-Process Acid?: The Impact of New Technology, National Fertilizer Development Center, TVA, p. 61-65.
9. Kimrey, J. O., 1965: Description of the Pungo River Formation in Beaufort County, North Carolina: Bul. 79, Div. of Mineral Resources, Dept. of Conserv. and Dev. (now Dept. of Natural and Economic Resources), 129 p.
10. Lewis, R. W., 1970: Phosphorus: Bul. 650, U.S.B.M., p. 1141.
11. Rooney, T. P., and Kerr, P. F., 1967: Mineralogic Nature and Origin of Phosphorite, Beaufort County, North Carolina: Bul. Geol. Soc. America, V. 78, p. 731-748.
12. Ruhlman, E. R., 1958: Phosphate Rock, Pt. 1: Inf. Cir. 7814, U.S.B.M., p. 10, 12, and 24.
13. Smith, R. W. and Whitlatch, G. I., 1940: The Phosphate Resources of Tennessee: Bul. 48, Tenn. Div. of Geology, 444p.
14. Wenneborg, et al, 1973: Method of Subterranean Drilling and Mining: U. S. Patent 3,730,592, 7 p.
15. Wenneborg, et al, 1973: Subterranean Slurry Mining Apparatus: U. S. Patent 3,747,696, 16 p.