

Paper to be presented at joint meeting of German Association of Metallurgists and Miners GDMB and Mining Association of Austria BVÖ in Innsbruck, Austria, May 17-20, 1978.

PHOSPHATE MINING IN NORTH CAROLINA

by

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The manuscript will be prepared in English; the presentation and possible discussion will be in German.

PHOSPHATE MINING IN NORTH CAROLINA

ABSTRACT

North Carolina is the youngest phosphate-producing state in the USA. After exploration of the rich Pungo River phosphate deposit by means of geophysics and core drilling, Texasgulf Inc. put the largest phosphate flotation and calcination plant in the United States in operation. The 12-meter-thick phosphate deposit is covered by 30 meters of overburden, lies under tidewater land, near Cape Hatteras, close to the Atlantic Ocean, and is mined with dredges and draglines in open-pit operation. The top thirteen meters of waste is removed from above the deposit with suction dredges and is pumped for land reclamation into mined-out areas. The rest of the overburden and ore is mined with draglines. Two hundred and thirty thousand cubic meters of water per day have to be pumped from the aquifer under the deposit to keep the pit dry. The flotation concentrate is calcined and converted to phosphoric acid, superphosphoric acid, diammonium phosphate, and triple superphosphate in modern, large capacity units. Applied mineral processing research at the North Carolina State University Minerals Research Laboratory in Asheville supported exploration and deposit evaluation for Texasgulf Inc. The flowsheet for the mill was developed through drill core investigations and pilot plant flotation testing. The Lee Creek phosphate complex is an example of large-capacity processing units with high mineral recovery, and of planning with environmental concern and for land reclamation. The geology of the deposit, mining, milling, phosphoric acid-fertilizer production, environmental protection and land reclamation will be presented and illustrated.

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LOCATION AND GEOLOGY OF THE NORTH CAROLINA PHOSPHATE DEPOSIT

One of the largest U. S. phosphate deposits is found on the east coast of the United States in and around Beaufort County, North Carolina (Figure 1). Estimates of up to 10 billion short tons (st) of phosphate pebble have been made for the North Carolina phosphate area. About 1.5 billion st of the North Carolina phosphate pebble is recoverable by today's mining and processing technology. The North Carolina phosphate formation was named Pungo River Phosphate Formation, it is of Middle Miocene Age, and it does not outcrop. ¹ The Pungo River Formation lies unconformably on a major aquifer, the Castle Hayne formation; it is overlain unconformably by the Yorktown formation and recent sediments; and it lies under tidewater land. The part of the deposit that can be mined by dry open pit typically is covered by 27-30 m (90 to 100 ft) of unconsolidated overburden, the upper 9-12 m (30 to 40 ft) being recent sandy sediments, and about 18 m (60 ft) are clay, silts and sands of the Yorktown formation and low-grade phosphatic-coquina caprock. The recoverable

part of the high grade phosphate deposit averages 11 m (35 ft) in thickness with 13 to 15% P_2O_5 (Figure 2). The approximate mineral content of the high grade ore is

45-50% phosphate pebble (francolite)

30-35% silica sand

15-20% clay and fine silt

5-10% free calcite, dolomite and other minerals

Texasgulf Inc. delineated the open-pit-minable part of the North Carolina phosphate reserve by gamma-ray logging of existing water wells and by core drilling and metallurgical test work in 1961-62, and controls now more than 35,000 acres (Figure 3). Texasgulf Inc. started commercial production of North Carolina phosphate in 1966 and is the only phosphate producer at this time (1978) in North Carolina.^{2,3,4} A second company, North Carolina Phosphate Corporation, has definite plans for large-scale production. Dresser Industries and FMC Corporation have also actively explored in the North Carolina phosphate area but have no announced plans for production. Two main problems had to be solved by Texasgulf (Tg) to bring the property into operation. First: mining of a relatively deep deposit, close to and under an ocean-connected tidewater body, down to 41 m (135 ft) below sea level, which is also underlain by a major fresh-water aquifer. Second: production of high-grade phosphate concentrate without contamination by calcium carbonate, coquina, shells, and dolomitic limestone found intimately mixed in the ore body.

MINING OF THE NORTH CAROLINA PHOSPHATE DEPOSIT AT
TEXASGULF INC. LEE CREEK OPERATION AND LAND RECLAMATION

The first samples of North Carolina phosphate ore were obtained by drilling wells into the deposit and flushing of the ore to the surface through the well casing. This material was used for early batch and pilot plant tests at the North Carolina State University Minerals Research Laboratory at Asheville, to examine the mineralogy of the concentrated pebble, a carbonate-fluor-apatite, and also to test the fertilizer chemistry. Reliable quantitative information about the matrix could not be obtained by this mining technique, which has been more extensively studied by FMC and Dresser Industries. Texasgulf Inc. core drilled the deposit in 1962 and verified and complimented earlier gamma-ray-logging data through geologic logs and beneficiation testing at the North Carolina State University Minerals Lab. ⁵ The data from 67 drill cores revealed a major phosphate deposit deeper than the mines operated in Florida, but with the same ratio of overburden to ore, and yields of 30,000 st of phosphate concentrate per acre, more than five times the concentrate tonnage per acre that was obtained in Florida at that time. The concentrate pebble had a slightly higher CaO/P₂O₅ ratio than Florida pebble and would consume about 8% more sulfuric acid in fertilizer production. The pebble was lower in iron and alumina, had higher reactivity, and produced an extremely pure phosphoric acid after removal of hydrocarbons and some CO₂ by calcining.

In order to thoroughly evaluate the deposit and the character of the overburden, approximately 100,000 st of ore was brought to the surface

by Tg at Lee Creek in 1964 employing a contractor's 50 cm (20 in.) hydraulic dredge. The ore slurry was captured in impoundment basins. Clays in the matrix that were liberated during the dredging operation were captured and measured in a secondary collection basin. The ore sample was then subjected to a variety of studies principal of which were pilot-plant-scale beneficiation, calcination, and acidulation testing at Lee Creek.

The test dredge was successively lowered 30 m (100 ft) in a 16-acre pit through the overburden, through the ore zone, to the aquifer contact. The stability of the overburden walls was studied, and a low point water pumping well system was established around the pit to gather pressure data in order to develop a computer model for soils stability. The Yorktown overburden formation which was very high in clay content, with a few other principal factors, led to the decision to employ the dragline mining method as opposed to the dredge method. The slurification of the Yorktown layer, which contains significant quantity of clay, by employing a dredge would have created an uncontrollable clay disposal problem because of the volume created since these clays do not readily dewater and compact. Montmorillonite, which is a principal clay contained in both the overburden and the phosphate matrix, has a significant swelling characteristic when slurified. The original mining scheme initiated in 1966 employed a 15 cubic meter (20 cu yd) Bucyrus-Erie 480 W dragline with a 53 m (175 ft) boom on the surface whose principal function is to feed the ore pumping system. The prime mining instrument was a 55 cubic meter (72 cu yd) Bucyrus-Erie 2550 W dragline with a 91 m (300 ft) boom located at the minus 9 m (-30 ft) elevation. This machine technically chopped down the upper

9 m (30 ft) of overburden and cast it into the pit to form a preliminary bulkwall. Next the Yorktown formation was cast behind the stabler upper 9 m (30 ft) in the spoil area. And finally the coquina cap rock located at the upper contact of the ore zone was cast to the bulkwall to provide stability (Figure 4).

At times because of variations in the stability of one or more of the members of the overburden strata, the sequence of stacking was reversed or modified. That is to say, the Yorktown might be stacked as the bulkwall and a less stable upper sand cast behind it. During several periods in the last decade, stability of the overburden became a serious problem, and it was necessary to leave a plug of ore as a bulkwall. Ore recoveries were only in the 60 to 80% range. While Tg was generally satisfied with the results of the dry-mining dragline system, when the time came to expand the mine, the opportunity to improve on the mining technique was taken. The three main objectives were: 1) Since the dragline is not designed to efficiently remove chopped-down material which is above its base, it was hoped Tg could improve its productivity by accomplishing this in some other manner. It was also essential to improve ore recoveries, if possible. 2) The mining system was to meet the demands of an efficient and satisfactory land reclamation program. 3) The most variable geological formation in the area is the upper 30 feet. At times it contains sufficient silts and clays of a nature to entirely modify the stackability of the entire spoils, and also there was much difficulty in supporting the surface ore pumping and mining equipment. A mining scheme that would remove this upper section of the overburden and transport it back behind the draglines

would accomplish all three of the improvement objectives while at the same time accomplish the mine expansion. After considerable study the comparison came down to a bucket-wheel conveyor-stacker system and a conventional dredging operation. The principal concerns about a bucket-wheel system were the ability to convey moist clay material without producing substantial buildup on the conveyor system and the problem associated with supporting the stacker in the spoil area, which had already demonstrated its instability. There were two problems associated with employing a dredge. The first concern was: could a dredging operation sweep the top 30 feet clean enough so that conventional dry-mining equipment could move in and operate on the base? The second problem was that of creating a clay disposal problem by slurrifying the clay in the upper 9 m (30 ft). After examination of the upper 9 m (30 ft), it was determined that the amount of clay in this zone was not sufficient to cause the problem. The dredging operation was started in 1976 with a 75 cm (30 in.) Ellicott electric suction dredge, and the draglines entered the first dredged cut in mid-1977 with very gratifying results. Ore recoveries in the mine are now routinely in the mid-90 percent range. The added dimension of replacing dredge spoil in the dragline spoil area allows us to efficiently and rapidly reclaim and restore land after mining. Freeing the draglines from the chopdown cut has significantly increased their productivity. The mine now employs a 75 cm (30 in.) and an auxiliary 50 cm (20 in.) suction dredge for overburden removal and land reclamation, and a 55 cubic meter (72 cu yd) Bucyrus-Erie dragline and a 38 cubic meter (50 cu yd) Marion dragline for overburden and ore removal, plus two auxiliary smaller draglines to feed the ore slurry pump sumps. Both large draglines

have booms of 91 m (300 ft) length. The dry open-pit mining method requires local depressurization of the ore body by pumping about 230,000 cu m (60 million gallons) per day of fresh water from the underlying Castle Hayne formation. ⁶ The Lee Creek mine can now easily provide the mill with 25,000-35,000 st per day of ore, and removes about 50,000-70,000 st of overburden per day (Figure 5). North Carolina Phosphate Corporation also will develop a large open-pit mine in that area but plans to strip 15 m (50 ft) of overburden by bucket wheel excavator and reclaimed stackers, and will mine the rest of the overburden and phosphate matrix by dragline.

Prior to the development and implementation of the dredge-dragline method of mining, land reclamation presented substantial materials handling tasks due to the irregular spoil piles left after dragline mining. The prestripping operation with the dredge now permits placing the pre-stripped overburden back into the spoil area left after mining, leveling valleys and gaps between the spoil heaps. While the dredging operation advances in front of the dragline operation removing the top 12 meters (40 feet), it discharges the material behind the dragline evenly, so restoring the mined-out land to a useable condition. The lack of substantial quantities of clay in the dredged overburden makes this scheme possible. At Lee Creek we are presently testing blending all of the waste products to form a stable land fill. At pilot-plant level we have been successful in blending the waste products from beneficiation, such as the coarse tailings, the clays from desliming and the gypsum from manufacturing phosphoric acid. We have demonstrated that we can pump, by conventional means, 60% solids blends as neutral slurries that hold slopes of 4 to 6%.

CONCENTRATION BY SIZING, FLOTATION, AND
CALCINING AT LEE CREEK

Because of the calcium and dolomitic limestone sections in the Pungo River formation, the concentration of North Carolina phosphate presents a problem. No reliable flotation method to separate phosphate from calcite and dolomite is known. If the whole phosphate section is treated by flotation after grinding of all phosphate pebble to flotation size, appreciable amounts of free calcite and dolomitic material enter the concentrate. This makes the material unacceptable for the fertilizer industry because of high sulfuric acid requirements in acidulation. Extensive metallurgical and mineralogical test work, with close attention to the geologic features of the deposit, resulted in four concentration steps to produce high-grade phosphate concentrate from the Pungo River formation. 7,8

- 1) Definition of only high-grade part of phosphate section for differential mining;
- 2) Removal of lime and clay from the high-grade phosphate section by sizing, scrubbing and desliming;
- 3) Removal of quartz from phosphate pebble by flotation;
- 4) Removal of water by drying, and removal of hydrocarbon and CO₂ by calcination.

Table I presents the typical tonnage distribution in the Pungo River phosphate formation. On the basis of low P₂O₅ and pebble content,

high free-calcium-carbonate content, and high ratio of concentration, the upper 11-foot section (76-87 ft) of the phosphate formation is defined as upper low grade to be removed as part of the overburden from the top of the ore bed. This upper low-grade section, in average 10 to 15 ft thick, is easily recognized in the pit because it contains a high percentage of light-colored hard coquina limestone indurated through the phosphate sand. (See Figure 2) The upper low grade contains, in the case presented, only 7% of the total P_2O_5 in the phosphate section but contains 53% of the free calcium carbonate in the section.

The footage section 87-127 ft has an average P_2O_5 content of 14.7% and high pebble content of 48%, a low CaO/P_2O_5 ratio, a low ratio of concentration of 2.1, contains only 25% of the free calcium carbonate in the section, and the calcium carbonate is mainly in the very fine size fraction and coarser fractions. This 40-ft thick section is defined as high-grade phosphate section. It contains 87% of the total P_2O_5 in the phosphate section, and is to be mined, slurried up and processed for phosphate recovery.

The footage 127-131 is lower in phosphate, and has a high free-calcium-carbonate content, 22% of the whole Pungo River section. This section is designated lower low grade. It also contains some magnesium carbonate, and it is left in the ground as a barrier against the underlying Castle Hayne aquifer.

The high-grade section is mined and milled as one section of up to 12 meters (40-ft) thickness, in spite of a thin layer of hard dolomitic clay stone in the upper 10 ft of this section. This hard dolomitic

limestone can be removed from slurried high-grade ore matrix by screening on 14 mesh. By taking some P_2O_5 losses in the relatively small amount of plus 14 mesh phosphate, 42% of the free lime and all of the coarse dolomitic material in the high-grade section is removed. Nearly all remaining free lime and dolomite, which is fine grained or soft, can be removed after wet scrubbing by desliming on 200 mesh. Table II demonstrates the lime removal by sizing and desliming from the high-grade section of the Pungo River formation, representing an average high-grade section thickness of 39 feet. The free-lime rejection from North Carolina phosphates consists of differential mining of one fairly well defined high-grade section, plus physical sizing of the slurried matrix on 14 mesh, and removal of minus 200 mesh clay and lime slimes after scrubbing. The hard North Carolina francolite phosphate pebble allows intensive scrubbing without deterioration of sand-size phosphate pebble into the slime. The removal of 16-18% by weight of slime with low P_2O_5 content up-grades the minus 14 plus 200 mesh flotation feed to about 17-18% P_2O_5 .

The further upgrading of the sized and deslimed phosphate-quartz mixture is done by flotation (see Table III). For the North Carolina phosphate, two different flotation systems and a combination of both systems can be employed for highest grade with high recovery. If the phosphate-quartz mixture is conditioned at neutral to slightly alkaline pH with an anionic tall-oil-type fatty acid collector of high rosin-acid content, partially pre-saponified and mixed with No. 2 fuel oil, a fair grade single-float concentrate with 26 to 29% P_2O_5 and with phosphate recoveries of over 95% can be obtained. Substantial amounts of phosphate-stained quartz and interlocked phosphate-quartz pebbles report in this

single-float concentrate. It is also possible to render the quartz hydrophobic and float it, plus stained and interlocked quartz, away from the phosphate with a cationic amine-type collector in neutral circuit. High concentrate grades of 30 to 31% P₂O₅ with fair recovery of 80 to 90% can be obtained. The amine system is very sensitive to slimes and reagent variations and causes operational problems also because the concentrate has to be removed as flotation machine underflow. There are also problems involved in floating the coarser quartz with the amine system without losing fine phosphate in the float waste product. The most reliable system for obtaining high-grade concentrates of 30 to 31% P₂O₅ with high flotation recoveries, is a combination of anionic tall-oil soap and fuel oil flotation followed by dereagentizing with sulfuric or weak phosphoric acid, and a cationic amine float. The cationic cleaner float removes the fine silica, phosphate-stained quartz, and interlocked particles from the anionic-floated rougher float. This double flotation method is used extensively in Florida where it was developed by Crago in 1941. ⁹

The single-flotation step only is used by Tg for all the phosphate concentrate used in the phosphoric acid plants. The extra reagents and treatment costs and phosphate losses of the amine flotation step are avoided, and the higher silica content of the lower-grade single-float phosphate concentrate does not negatively affect filter performance in the phosphoric acid plant. It apparently reduces corrosiveness by reaction with hydrofluoric acid generated during acidulation. The double-flotation step is only used for phosphate concentrate to be sold and for some in-house use. The concentrator at Lee Creek has a capacity of 10,000 to 12,000 st per day of concentrate from 25,000 to 30,000 st per day of

matrix. Extensive water recirculation is practiced through the use of three 91-meter (300-ft) diameter thickeners, and a 57,000 cubic meter (15 million gallon) mill water pond. The total mill water requirements are about 500 cubic meter/min (65,000 gpm), but only 150 cubic meter/min (20,000 gpm) have to be made up as fresh water, mainly for pump gland water and for the slime-sensitive amine flotation circuit (Figure 6). Waste slimes are pumped at 6-8% solids to a 700-acre settlings pond about 8 km (5 miles) away.

The flotation concentrates are further upgraded by drying to remove free water and by calcining at around 820° C (1500° F) in a fluidized bed. Calcining removes the small amount of hydrocarbons found in North Carolina phosphate pebble and removes some of the CO₂ from the pebble. Calcination eliminates foaming during acidulation, and calcination contributes to the production of a high-grade, sludge-free, clear light-green phosphoric acid. An upgrading of the concentrate to a grade competitive with Florida phosphate is achieved. A savings in shipping costs proportionate to weight loss of about 10% is obtained by calcination (see Table IV). Drying and calcination is performed in fluosolid calciners with heating and cooling heat-exchange beds. Tg has now six fluosolid calcining units in operation, with a capacity of close to 9,000-10,000 st per day. It is the world's largest calcining plant. 10,11,12,13 (Figure 7)

COMPARISON WITH FLORIDA PHOSPHATES

The Florida phosphate field is the principal producer of sedimentary marine pelletal phosphate in the USA. Comparison of North Carolina phosphates with Florida phosphates in respect to geology, mineralogy, mineral processing and chemical processing was made by Tg^{8,14} and led to important differences in the processing of North Carolina phosphates for wet-process phosphoric acid production. The geology favors North Carolina with a fairly uniform, unweathered deposit of large reserves, and high tonnage of recoverable concentrate per acre. About 4 to 8 times the amount of phosphate recovered per acre in Florida, allows deeper mining and more costly dewatering of the mine pit. Less acres of lower-valued surface than in Florida have to be disturbed for equal phosphate production. The mineralogy of North Carolina phosphate allows advantageous deviations from Florida phosphate concentration practice. Most of the North Carolina phosphate values are in a fine flotation-size pebble, minus 14 mesh plus 200 mesh, and are of very uniform round size and are of uniform grade. In Florida, coarse salable phosphate rock, minus one inch plus 14 mesh, is recovered by disintegrating, washing, and screening. The minus 14 mesh plus 35 mesh phosphate pebble is recovered by film agglomeration flotation on belts, spirals, shaking tables or special air flotation machines. The minus 35 mesh plus 200 mesh fraction is recovered by the Crago double-flotation procedure. There are three different phosphate processing and product handling operations in use in Florida. The North Carolina phosphate pebble allows all-flotation of the minus 14 mesh plus 200 mesh feed in one operation with high recoveries. The North Carolina phosphate

pebble is quite hard and nonweathered and allows intensive scrubbing and desliming for flotation feed preparation. Only a very small amount of phosphate values is lost in the North Carolina slime. In Florida up to one-third of the phosphate values in the matrix are lost in the slimes. To render the North Carolina phosphate pebble hydrophobic for flotation, a pre-saponified high tall-oil fatty acid with high rosin-acid content (Westvaco M-28 or equivalent) is employed together with No. 2 fuel oil. The reagent amounts, the percent solids, the retention time and the pH values in the conditioner can fluctuate over a fairly wide range using the North Carolina phosphate flotation system. In spite of feed-rate and feed-grade fluctuations, a uniform grade of fatty-acid rougher-flotation concentrate (single-flotation concentrate) can be obtained with very high phosphate recoveries. The reagent consumption is quite low because of efficient surface preparation, good slime removal, and good dispersion of pre-saponified fatty acid and fuel oil, and possibly because of the more reactive nonweathered phosphate pebble. The lower density in the conditioner reduces power consumption and wear. In Florida, flotation conditioning is usually done at high percent solids (plus 70%), and at a high and critical pH value, obtained by adding caustic or ammonia to the conditioner, together with tall oil or tall oil heads and No. 5 fuel oil. The high percent solids in the conditioner of Florida phosphate plants, together with a softer phosphate pebble adversely affects flotation recoveries at times because of slime formation. The calcium oleate-hydrocarbon film which has to be removed from the fatty-acid rougher-flotation concentrate prior to belt transport and storage, or prior to treatment by the reverse amine-flotation step, is easier to remove from the North Carolina phosphate

pebble with less sulfuric acid or waste phosphoric acid. This is partly because of the more uniform reagent coverage and partly because of the higher reactivity of the North Carolina phosphate pebble.

Because of the higher hydrocarbon content and higher carbonate content, calcining at about 820° C (1500° F) upgrades the North Carolina phosphate concentrate by complete removal of hydrocarbon and by partial removal of the carbonate CO₂ content. The hydrocarbon in the pebble contributes appreciable amounts of the calcining heat requirement. Calcining of North Carolina phosphate concentrates prevents foaming in the phosphoric-acid-plant reactor;

and makes possible the production of a light-green clear phosphoric acid without sludge. The superphosphoric acid is of nearly animal-feed-grade quality. Calcining of double-flotation concentrate produces a saleable phosphate comparable to 72 BPL Florida pebble phosphate, with advantages over Florida such as low iron, alumina, and silica content. The high reactivity of North Carolina phosphate eliminates the need for fine grinding before acidulation. Calcining makes it possible to use the lower-grade single-flotation concentrate with high silica content (8-10%) in the captive phosphoric acid plant.

PHOSPHORIC ACID, SUPERPHOSPHORIC ACID,
TRIPLE SUPERPHOSPHATE AND DIAMMONIUM PHOSPHATE
PRODUCTION AT LEE CREEK

At Lee Creek a large percentage of the phosphate concentrate is converted to plant food in Tg's phosphoric acid plants. Sulphur from Tg's operations in Texas, Mexico, Louisiana, and Canada is shipped to Lee Creek and converted to sulphuric acid in four large sulphuric acid contact-acid plants.



The acid is then used to digest calcine rock concentrates to produce phosphoric acid and an insoluble gypsum waste product in four phosphoric acid plants. The phosphoric acid manufactured at Lee Creek is of the highest quality in the market place. Steam produced as a by-product from the manufacture of sulphuric acid is used to evaporate and concentrate the phosphoric acid to 54%-P₂O₅ acid, which, after clarification, is marketed.



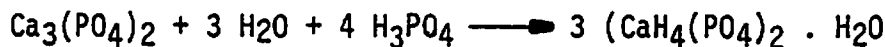
The 54% acid is evaporated to 69%-P₂O₅ superphosphoric acid which is ready for market or further processed to low-magnesium superphosphoric acid by filtration with rotary vacuum precoat filters to remove an iron-magnesium phosphate complex. Tg is the leading producer of superphosphoric acid in the world, and produces the highest-quality superphosphoric acid.¹⁵



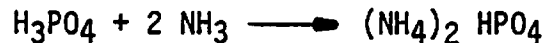
Example: $2 \text{H}_3\text{PO}_4 - \text{H}_2\text{O} \longrightarrow \text{H}_4 \text{P}_2\text{O}_7$ (Pyrophosphoric acid)

$4 \text{H}_3\text{PO}_4 - 3\text{H}_2\text{O} \longrightarrow \text{H}_6 \text{P}_4\text{O}_{13}$ (Tetraphosphoric acid)

The Lee Creek chemical complex contains facilities for manufacturing 510,000 stpy of granular triple superphosphate (GTSP). This product is manufactured by reacting phosphoric acid with ground double-flotation phosphate rock and granulating the resulting slurry.



Lee Creek also has the facility for manufacturing 200,000 stpy of DAP. Anhydrous ammonia is reacted with phosphoric acid to produce a slurry which in turn is granulated and dried.



By-products at the Lee Creek chemical complex include the marketing of 100,000 stpy of gypsum as a peanut soil conditioner and 6,000 stpy of 100% hydrofluosilicic acid which is recovered during the concentration of the phosphoric acid. Lee Creek is a major supplier of hydrofluosilicic acid in the United States for drinking water treatment.



The Lee Creek mine, mill and calcining plant supply one of the world's largest fertilizer complexes with phosphate-rock raw material. A schematic fertilizer complex flowsheet is presented in Figure 8. The capacity of the different interconnected units is reported as follows.

CAPACITY OF MINE, MILL AND FERTILIZER PLANTS (1978)

	<u>Short Tons/Year</u>
Mine Overburden Removal	22,500,000-30,000,000
Mine, Phosphate Matrix 13-15% P ₂ O ₅	7,500,000-10,000,000
Flotation Concentrate 27.5-30.5% P ₂ O ₅	3,000,000- 4,000,000
Drying	1,600,000
Grinding	1,200,000
Calcining	2,850,000
Sulfuric Acid 100% H ₂ SO ₄	2,100,000
Phosphoric Acid 54% P ₂ O ₅	1,260,000
Phosphoric Acid 100% P ₂ O ₅	680,000
Granular Triple Superphosphate 46% P ₂ O ₅	510,000
Diammonium Phos. Gran. 18% N, 46% P ₂ O ₅	220,000
Superphosphoric Acid 70% P ₂ O ₅	385,000
Hydrofluosilicic Acid 23%	26,000
By-Product Gypsum	3,400,000

TRANSPORTATION AND SHIPPING

Shipping from Lee Creek is effected by water, rail and truck. The state of North Carolina built an 8 km (5-mile) access road. Fifty-one km (32 miles) of railroad track had to be built by Norfolk and Southern Railway Company to connect Lee Creek. A 1,500 meter (5,000 ft) hard-surfaced landing strip gives Lee Creek fast connection by private aircraft. Tg has its own fleet of 700 rail cars for transport of phosphoric acid, hydrofluosilicic acid, and dry fertilizer material. Four self-unloading barges, 2,000-st capacity each, are used to move phosphate concentrate and dry fertilizer products to the shipping port of Morehead City, which is connected to Lee Creek via 93 km (58 miles) of intracoastal waterway. A 2,400-hp tow boat is on lease to Tg. Twenty one thousand five hundred st of phosphate can be moved by two shuttle tows every three days. At Morehead City, the North Carolina State Ports Authority provided protected storage facilities for 100,000 st of dry fertilizer material and bulk-carrier loading facilities with 2,500 stph loading rate from the storage. The bucket-wheel reclaimer, and shiploading system, was furnished by Krupp/Ardelt. The largest single shipment ever made from a North Carolina port left Morehead City in March 1978 in form of 44,998 st of calcined phosphate rock on the M/V Carlova. Five records for largest shipments from a North Carolina port were set by Tg's Lee Creek operation in 1977. Tg also ships phosphoric acid by rail from Lee Creek to Morehead City where tank storage and loading facilities for 20,000 lt of acid for overseas export shipments are provided.

Sulfur is received and stored in the liquid state at Tg's sulfur terminal at Radio Island, Beaufort, North Carolina, in two 14,500 lt storage tanks. Tg has its own fleet of three 23,000 lt sulfur tank ships for transport from Tg facilities in Beaumont, Texas and Coatzacoalcos, Mexico. The liquid sulfur is then transported in two Tg-owned barges of 2800 lt from Morehead City to Lee Creek on an as-needed basis. For contingency purposes, a vat of solidified sulfur is maintained at Lee Creek. Lee Creek is now the largest sulfur customer of Texasgulf Inc. (formerly Texas Gulf Sulphur Company), consuming more than 680,000 st of sulphur per year.

ENVIRONMENTAL PROTECTION

The Lee Creek Mining-Fertilizer-Chemical complex is one of the largest complexes of its type in the world. When the plants were built in the mid-60's, the latest available pollution-control technology was employed in all of the facilities as they were installed. In addition to these initial efforts, additional improvements have been made in the systems to further improve the pollution-abatement facilities. One of the major developments is the establishment of a totally-closed recycle system for the acid-pond water. In 1974, Tg working with the N. C. Division of Environmental Management designed a system which allows for no discharge of these pond waters. In order to accomplish this goal, the cooling systems in the phosphoric acid production units were re-designed, and we are now consuming acid-pond water in these facilities where fresh water had been used previously. This system was placed in service in 1974 and has been studied by the U. S. Environmental Protection Agency for its uniqueness and is now being suggested as a model for other phosphate companies.

Another area of environmental concern in which Tg is pioneering is the field of land reclamation. Experiments are conducted to utilize the ore clay fractions, the sand tailings, and the by-product gypsum from the phosphoric acid production units in the land reclamation programs. Some results are very encouraging. With the new mining method and mixing of gypsum into the overburden, more acreage can be reclaimed per year than is mined, and land mined during previous years is now reclaimed. The reclaimed land is put to productive use, for cattle grazing and crop raising.

Timber will be grown on selected tracts, and aquaculture has potential. The departments of agriculture and forestry of North Carolina State University made recommendations for best uses of reclaimed land.

All calciners, the sulfuric acid plants, the phosphoric acid plants, the fertilizer plants, and transfer points at storage and loading facilities are provided with up-to-date air-pollution control equipment. The plant is also monitored by a multitude of pollution detection devices at the plant site and in the surrounding area. The water quality in the aquifer is monitored by a large number of instrumented water wells, spaced up to 22 miles from the plant. A special Ecology Research Laboratory to measure the industry's impact on Pamlico Sound was also established by Tg and is still supported by the company, though operated now by East Carolina University.

The total capital expenditure for environmental equipment at the Lee Creek complex is in excess of \$16 million.

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TABLE I
 TONNAGE PUNGO RIVER FORMATION

<u>FOOTAGE</u>	<u>TONS/ACRE</u>		<u>% OF</u>		
	<u>MATRIX</u>	<u>P₂O₅</u>	<u>FREE CaCO₃</u>	<u>P₂O₅</u>	<u>FREE CaCO₃</u>
76 - 87	21,560	860	7,160	7	53
87 - 127	76,000	11,180	3,420	87	25
127 - 131	7,840	730	3,030	6	22
76 - 131	105,400	12,770	13,610	100	100

TABLE II
PROCESSING BY SIZING AND DESLIMING

MATERIAL	TONS/ACRE		% OF		
	PRODUCTS	<u>P205</u>	<u>FREE CaCO3</u>	<u>P205</u>	<u>FREE CaCO3</u>
+14 OVERSIZE	5,900	1,070	1,440	10	42
-14+200 FLOT. FEED	57,900	9,730	0	87	0
-200 SLIMES	12,200	380	1,980	3	58
PLANT FEED	76,000	11,180	3,420	100	100

Table III. Processing of Highgrade Minus 14 P

<u>Material</u>	<u>% Wt</u>	<u>st/acre</u>	<u>P₂O₅</u>		<u>CaO</u>
			<u>%</u>	<u>% of</u>	<u>%</u>
-14+200 flotation feed	100.0	57,900	16.8	100.0	26.8
Single flotation tails	43.3	25,100	1.4	3.6	1.5
Single flotation conc	56.7	32,800	28.5	96.4	46.1
Amine flotation tails	4.8	2,800	7.0	2.0	11.1
Double flotation conc	51.9	30,000	30.7	94.3	49.1

(a) Flotation conditions

<u>Process</u>	<u>Retention time (min.)</u>	<u>% Solids</u>	<u>pH</u>
Screening on 14 mesh	-	-	-
Desliming on 200 mesh	-	-	-
Scrubbing	3-5	60-65	-
Desliming on 200 mesh	-	-	-
Conditioning	5-8	50-60	7-8
Anionic fatty acid flotation	3-6	25-30	7-7.5
Acid scrubbing	3-5	50-60	2.5-3.0
Desliming on 200 mesh	-	-	-
Cationic amine flotation	3-6	25-30	7-7.5

lus 200 Mesh Material by Flotation (a)

<u>MgO</u> %	<u>Fe₂O₃</u> %	<u>Al₂O₃</u> %	<u>Insol</u> %	<u>Phosphate</u> pebble	<u>CaO/P₂O₅</u> ratio
0.5	1.1	0.3	44.6	54	1.59
0.4	1.4	0.1	93.0	5	1.07
0.6	0.9	0.4	7.7	92	1.61
0.6	-	-	65.8	23	1.59
0.5	0.7	0.4	2.3	99	1.59

Reagents in lb/ton of plant feed

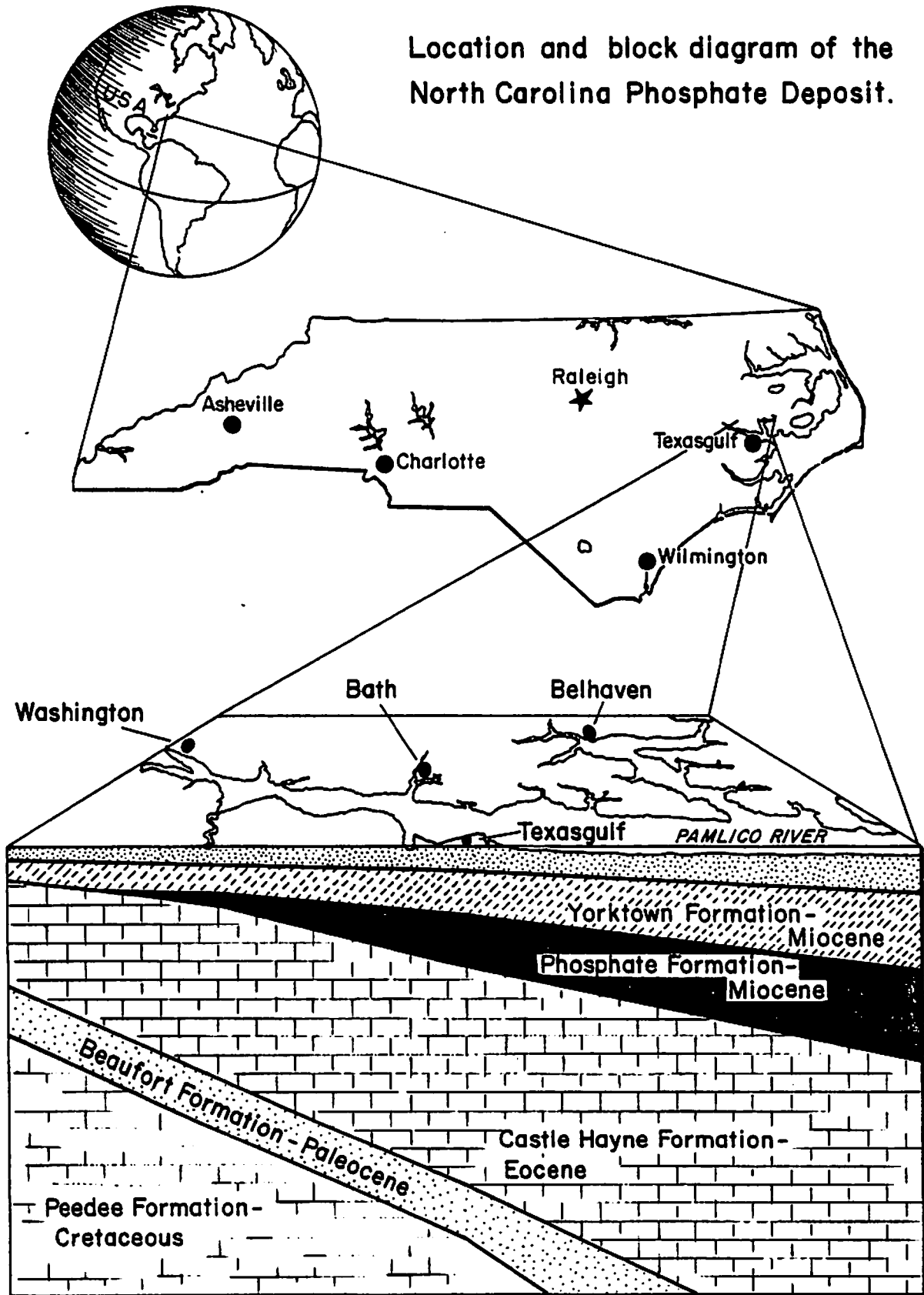
<u>Tall oil</u>	<u>NaOH</u>	<u>#2 Fuel oil</u>	<u>H₂SO₄</u>	<u>Amine</u> <u>acetate</u>	<u>Kerosene</u>	<u>Frother</u>
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
0.4-0.8	0.04-0.1	0.5-1.0	-	-	-	-
-	-	-	-	-	-	-
-	-	-	2-3	-	-	-
-	-	-	-	-	-	-
-	-	-	-	0.1-0.2	0.1-0.3	0.01-0.05

TABLE IV

PROCESSING BY CALCINING

	<u>% P₂O₅</u>	<u>% CAO</u>	<u>% MGO</u>	<u>% FE₂O₃</u>	<u>% AL₂O₃</u>	<u>% INSOL</u>	<u>CAO/P₂O₅</u>
FATTY ACID CONC	28.5	46.1	0.6	0.9	0.4	7.7	1.61
F.A.C. CALCINED	29.5	47.2	0.5	0.7	0.4	8.6	1.60
AMINE CONC	30.7	48.7	0.5	0.7	0.4	2.1	1.59
A.C. CALCINED	33.1	53.2	0.5	0.8	0.4	2.1	1.61

FIGURE 1. REDEKER - WRIGHT. LOCATION AND BLOCK DIAGRAM OF THE NORTH CAROLINA PHOSPHATE DEPOSIT



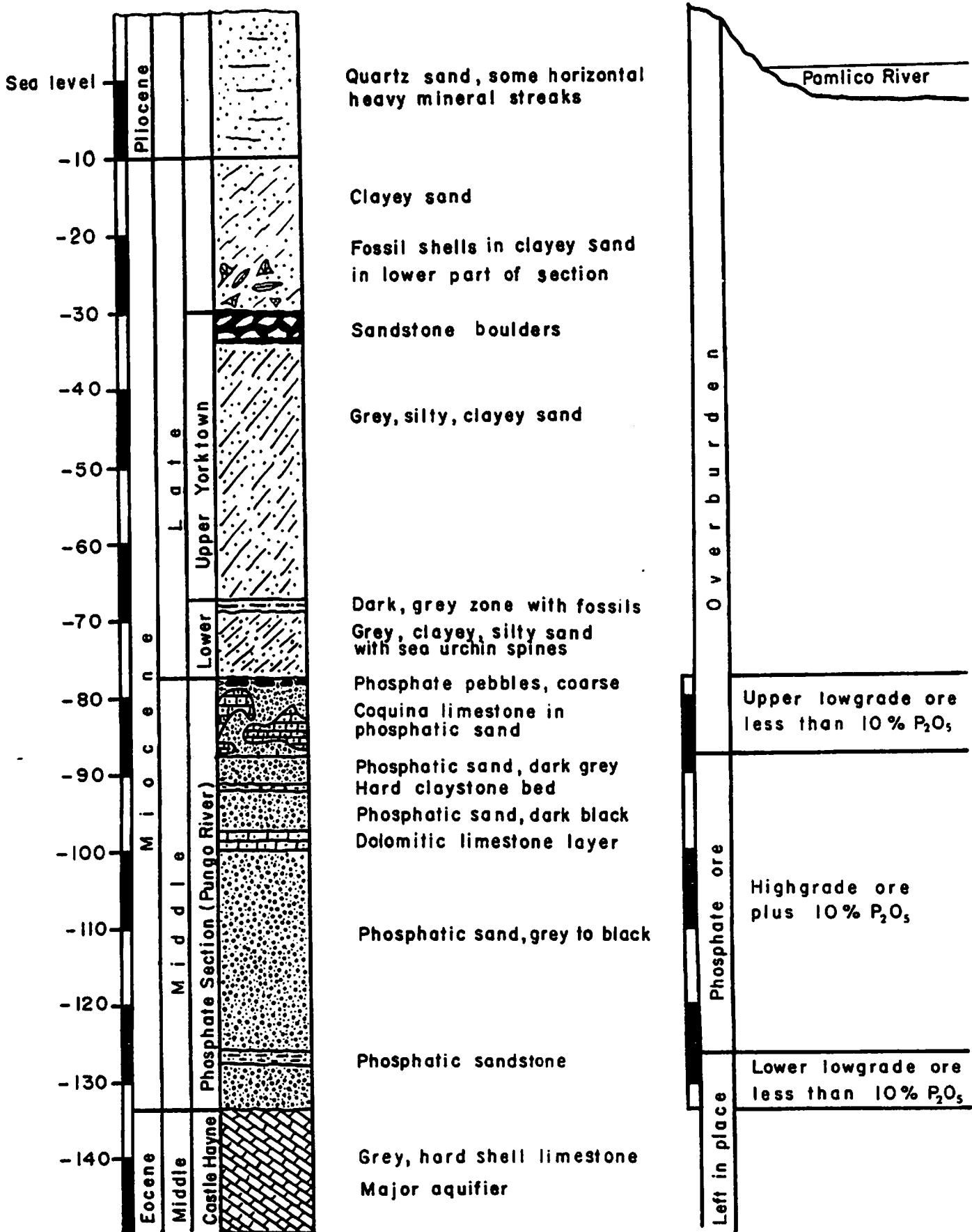
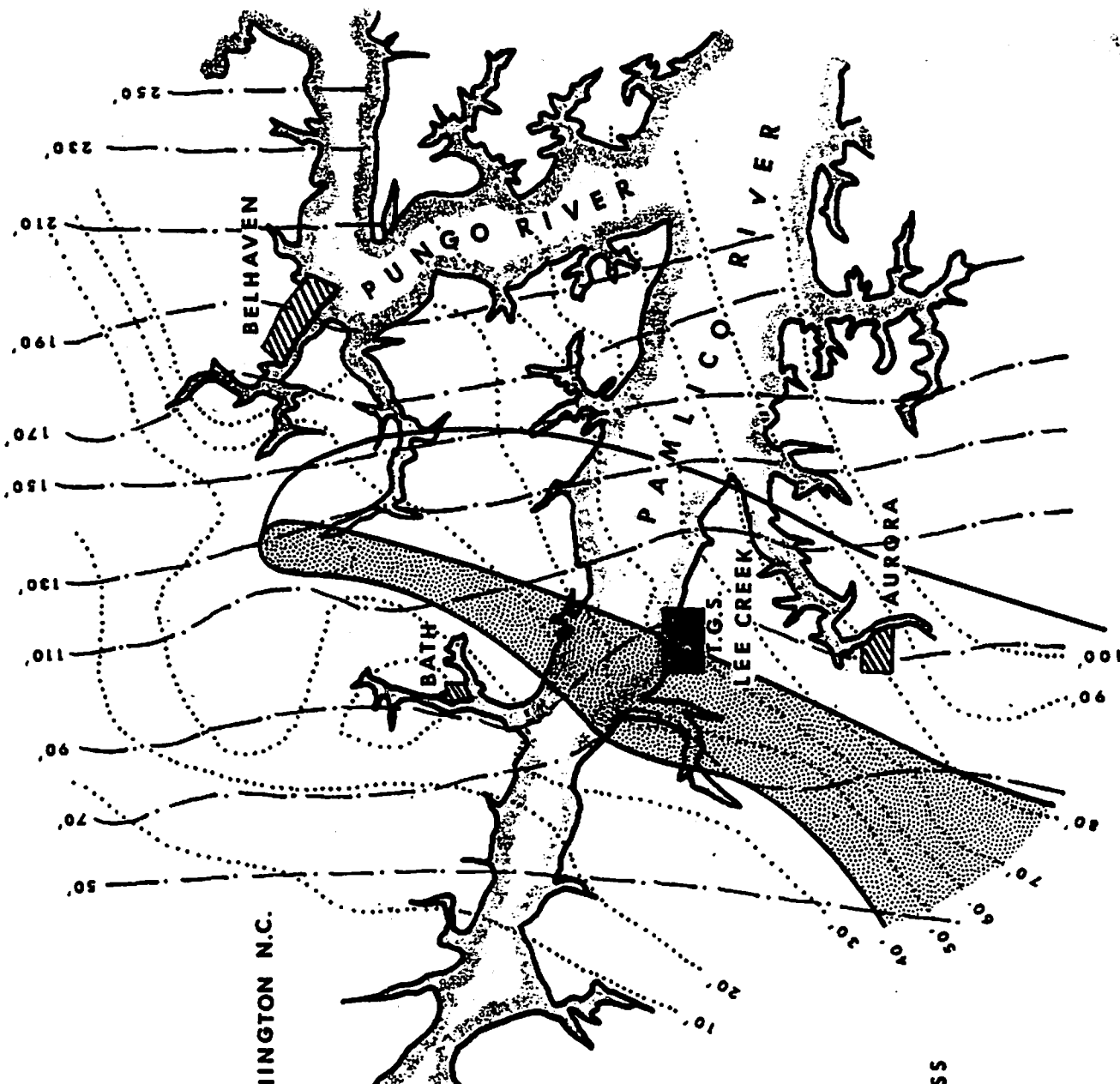


FIGURE 2. REDEKER - WRIGHT. GEOLOGIC SECTION NORTH CAROLINA PHOSPHATE



**PHOSPHATE AREA
BEAUFORT COUNTY N.C.**

..... PHOSPHATE FORMATION
 -.-.- OVERBURDEN THICKNESS

0 1 2 3 4 5 MILES
 SCALE

FIGURE 3

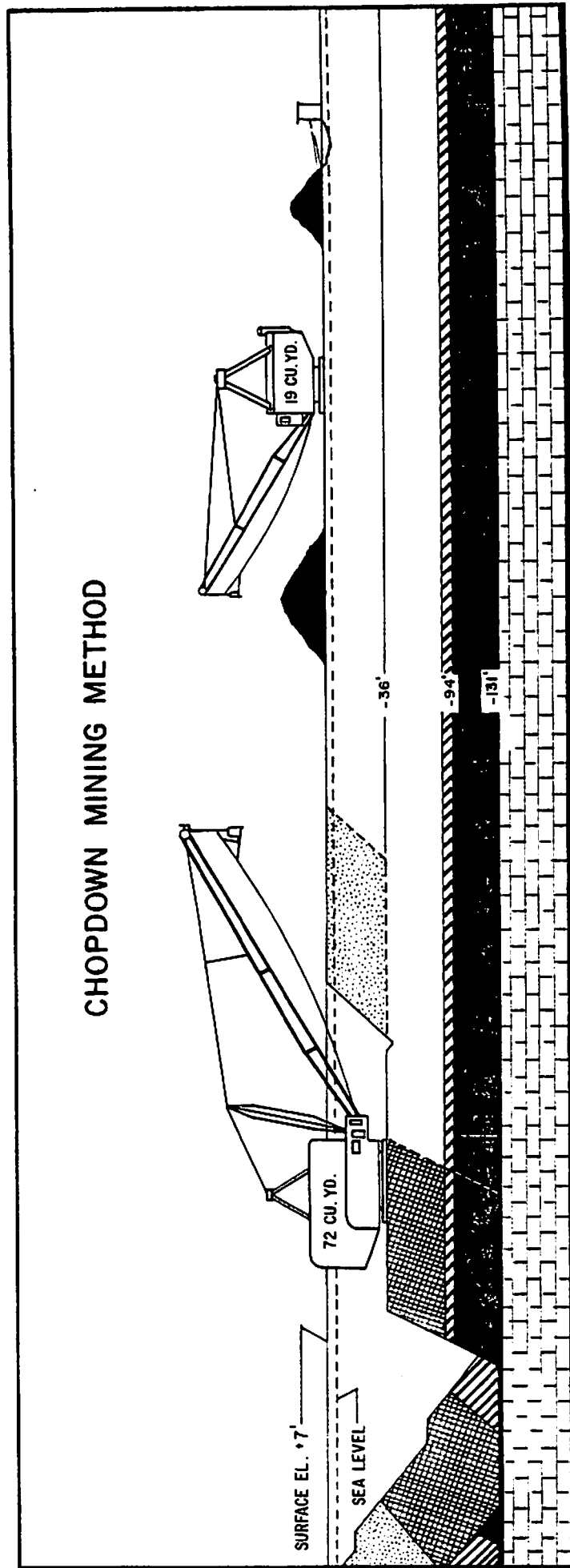


FIGURE 4. REDEKER - WRIGHT. CHOPDOWN MINING METHOD

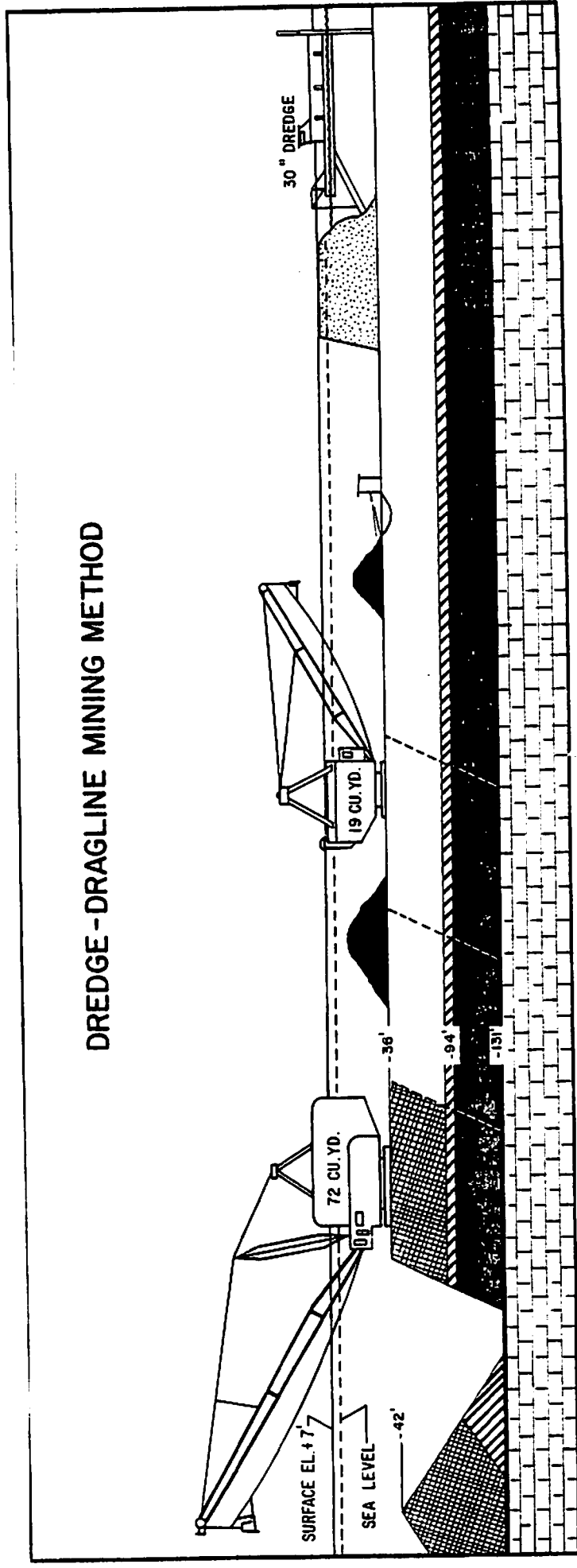


FIGURE 5. REDEKER - WRIGHT. DREDGE DRAGLINE MINING METHOD

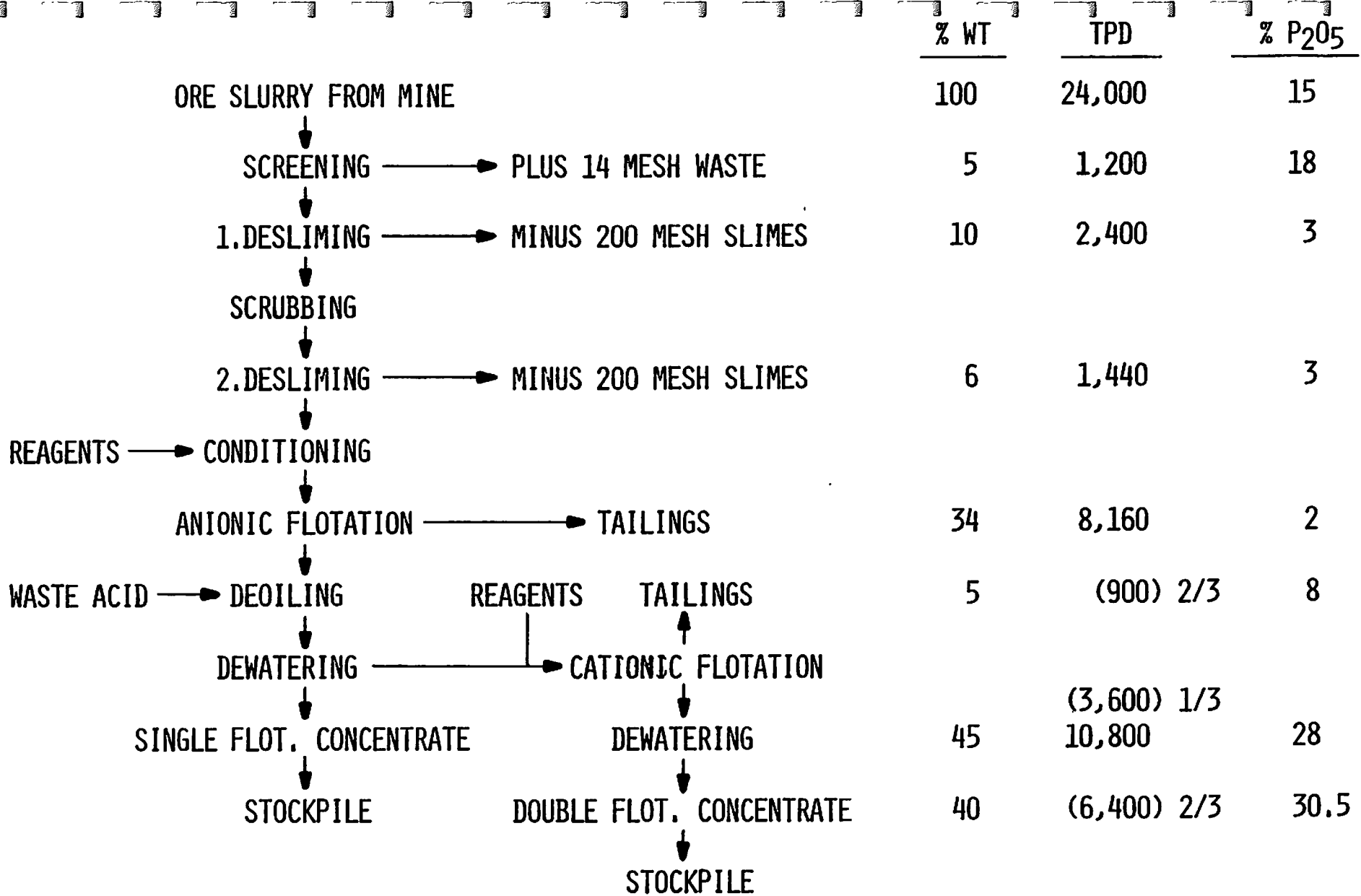


FIGURE 6. REDEKER - WRIGHT. LEE CREEK FLOTATION PLANT FLOWSHEET AND MATERIAL BALANCE.

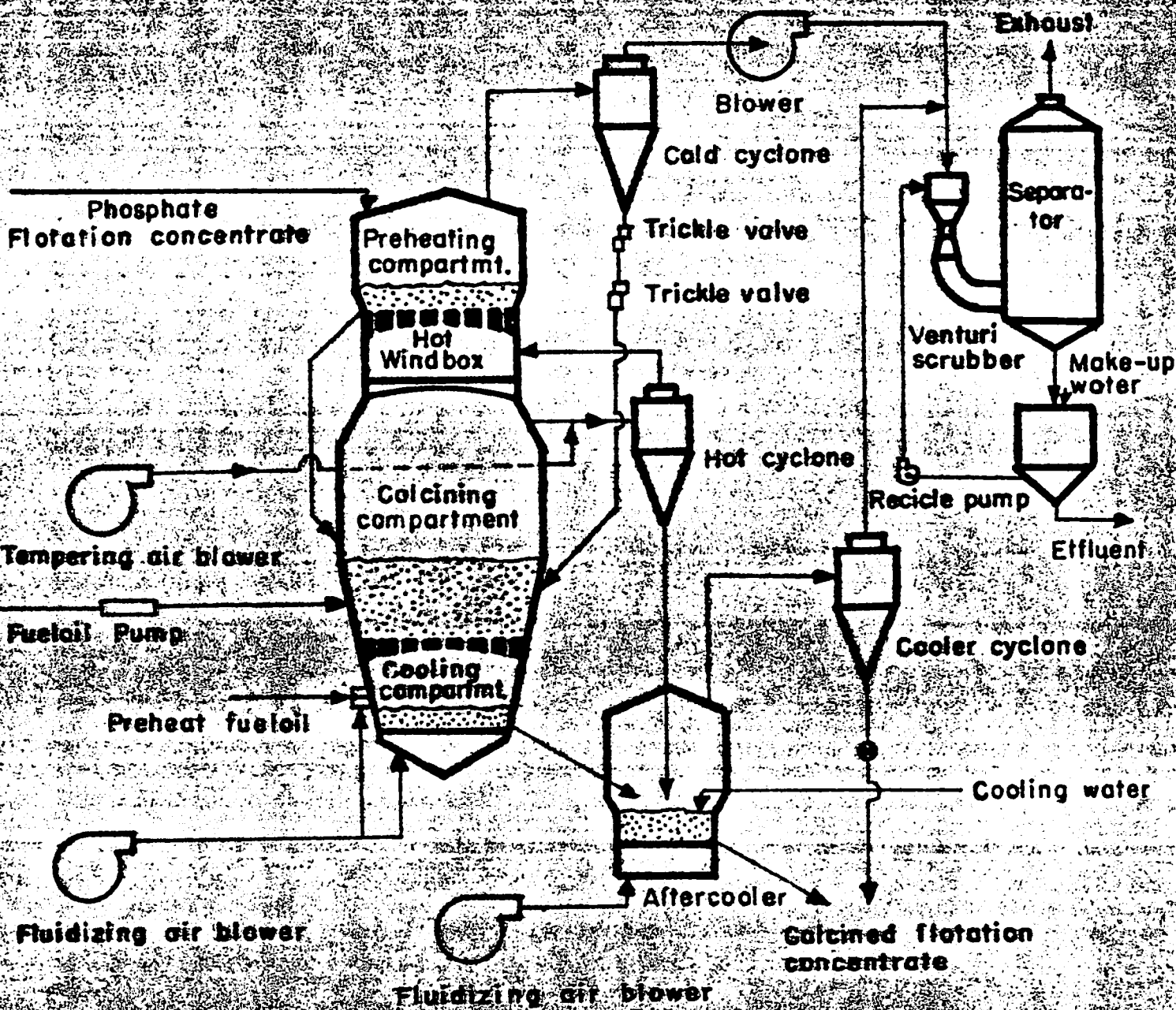


FIGURE 7. REDEKER & WRIGHT, FLUID BED PHOSPHATE CALCINER (SCHEMATIC)

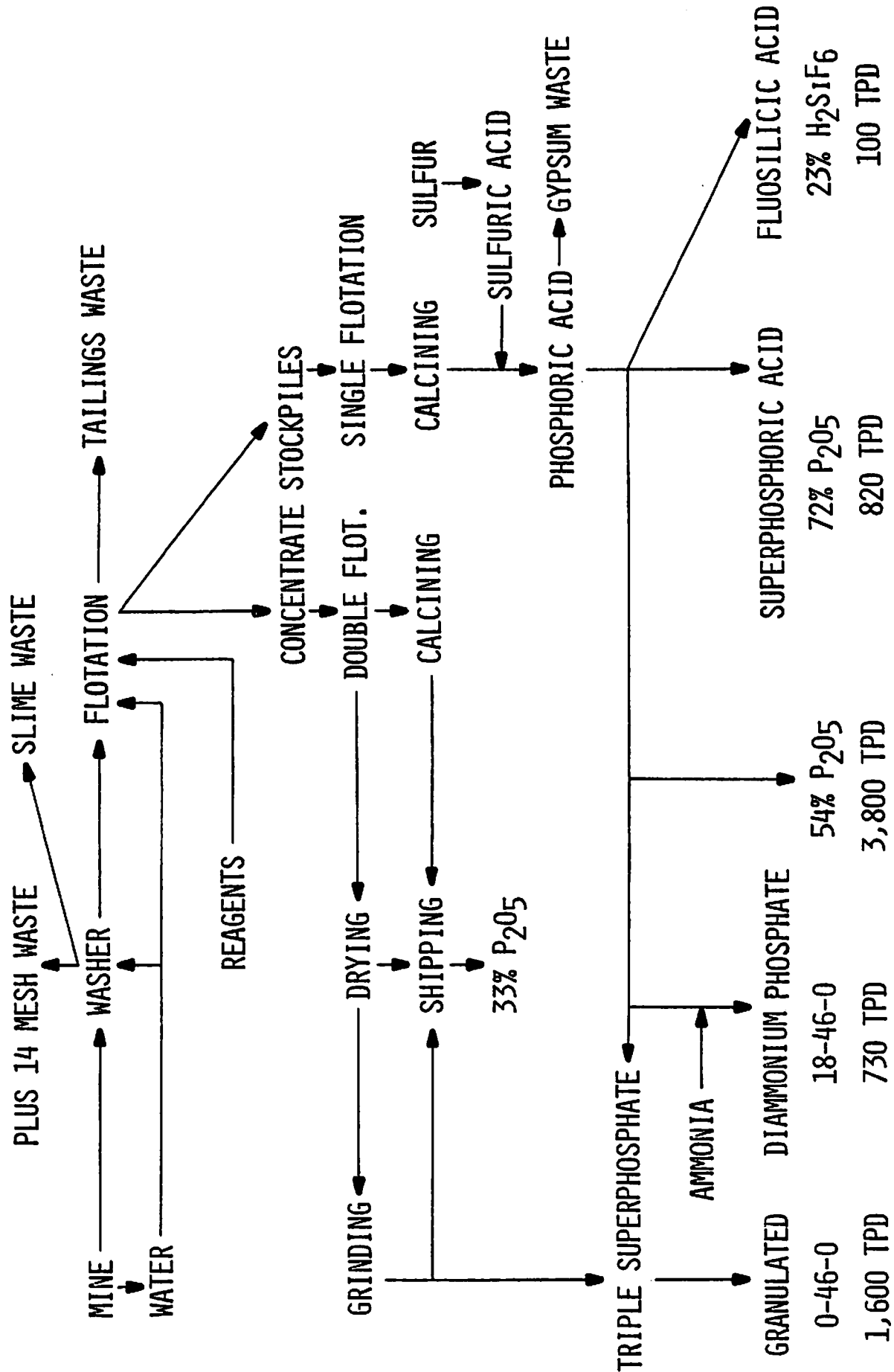


FIGURE 8. REDEKER - WRIGHT. LEE CREEK FERTILIZER COMPLEX FLOWSHEET (SCHEMATIC)