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Economic Evaluation of Borehole and Conventional Mining Systems in Phosphate Deposits

By Joseph A. Hrabik and Douglas J. Godesky

UNITED STATES DEPARTMENT OF THE INTERIOR
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Robert C. Horton, Director

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

bhp	brake horsepower	psi	pound per square inch
ft	foot	rpm	revolution per minute
gpm	gallon per minute	scfm	standard cubic foot per minute
hp	horsepower	tph	ton per hour
h	hour	V ac	volt, alternating current
in	inch	yd	yard
kW•h	kilowatt hour	yd^3	cubic yard
lb	pound	yr	year
lb/ft^3	pound per cubic foot		
pct	percent		

ECONOMIC EVALUATION OF BOREHOLE AND CONVENTIONAL MINING SYSTEMS IN PHOSPHATE DEPOSITS

By Joseph A. Hrabik [1] and Douglas J. Godesky [2]

ABSTRACT

The Bureau of Mines compared the feasibility of mining deep phosphate deposits by a borehole mining system with mining by proven conventional techniques. An economic comparison of the borehole mining system with conventional dragline and bucket wheel excavator mining systems was completed at various mining depths and production rates. Hypothetical phosphate deposits, with various overburden thicknesses and reserve tonnages, were defined. Geologic conditions necessary for the application of the borehole system were identified. Discounted cash flow analyses based on derived capital and operating costs were used to generate rates of return and product prices.

Borehole mining was found to be more economical where overburden thickness was 150 ft or greater; however, at 50- and 100-ft thicknesses, conventional surface mining was more economical. Overburden thickness has a great effect on the economic feasiblity of the conventional mining systems but less effect on the economics of borehole mining. Economies of scale are only realized in conventional mining, since larger equipment is employed to achieve greater production, whereas increased production from borehole mining is achieved using additional equipment units.

A comparison of the environmental effects of borehole and conventional surface mining systems showed that borehole mining is environmentally more desirable.

[1] Mining engineer, Eastern Field Operations Center, Bureau of Mines, Pittsburgh, PA.
[2] Physical scientist, Eastern Field Operations Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The phosphate mining industry of the United States is centralized in Florida where shallow sedimentary deposits have lent themselves to open pit mining. Total mining depths of less than 60 ft have made dragline mining the standard method of removing overburden and extracting phosphate ore (matrix). In areas where thicker unconsolidated overburden is encountered, dredges and bucket wheel excavators can be employed to assist in the removal of overburden.

As shallow phosphate reserves are depleted, deeper deposits are being considered for development. Recovery of these deeper deposits by conventional surface mining methods would require the removal of thick overburden that could result in higher costs as well as increased environmental disturbance. Some of the deep deposits, such as those in northeastern Florida, are immediately overlain by beds of semiconsolidated to consolidated rock. Under these circumstances, borehole mining may be a technologically and economically viable alternative to conventional mining.

This Bureau of Mines study evaluates the economics of borehole and conventional mining systems as applied to the recovery of hypothetical phosphate deposits. The extent of these deposits is assumed to be sufficient to justify capital expenditures at various production rates.

Borehole mining is a proposed method of recovering ore without overburden removal. The development of the borehole mining system for recovering a variety of minerals began early in the 20th century and continues to the present day. The most recent work was carried out by the Bureau of Mines under contract J0205038 (4).[3] The applicability of the borehole mining system for recovering phosphate matrix was tested using the Bureau's experimental borehole mining equipment at Agrico Chemical Co.'s property in St. Johns County, Florida. A prototype borehole mining system with updated specifications was designed as part of the contract, and is the basis for the borehole mining parameters and costs used in this study. The prototype system has not yet been built or tested.

A beneficiation process is proposed to concentrate primary phosphate matrix similar to that found in northeastern Florida. This high-grade phosphate matrix contains little pebble material and has a clay content averaging about 25 pct. Washing and double-stage flotation is proposed to produce a marketable phosphate rock product. The beneficiation process is assumed to utilize advanced clay dewatering methods to reduce disposal area volume requirements.

Results of the economic evaluation, at various mining depths and production rates, are graphically illustrated. These graphs can aid in the selection of a mining method whenever actual geologic conditions are similar to the hypothetical deposit situations depicted in this study. The graphs may also be helpful in assessing the sensitivity of mine economics to depth and production rate variations.

ACKNOWLEDGMENTS

Thanks are extended to Dr. G. S. Knoke, research scientist, Flow Industries, Inc., Kent, WA, and Dr. G. A. Savanick, physicist, Bureau of Mines, Minneapolis, MN, for providing technical details and costing parameters of the prototype borehole mining system. Grateful acknowledgment is made to Mr. M. F. Dibble, manager, new projects, Agrico Chemical Co., Tulsa, OK, and Mr. C. K. Brown, senior staff geologist, Agrico Chemical Co., Mulberry, FL, for their cooperation and technical assistance. Consultation with Mr. J. M. Williams, vice president and

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

general manager, Zellars-Williams, Inc., Lakeland, FL, greatly contributed to the analysis of conventional surface mining alternatives.

RESOURCE AVAILABILITY

Phosphate deposits suitable for recovery by the borehole mining system are located at structurally and cyclically favorable depositional sites along the southeastern coastal plain of the United States. The borehole mining system, if commercially applicable, could result in the recovery of billions of tons of phosphate resources.

DEPOSIT ASSUMPTIONS

For the purposes of this evaluation, criteria for a set of hypothetical deposits were established. Borehole and conventional dragline and bucket wheel mining systems were applied to the same criteria.

All deposits described are hypothetical and are not intended to accurately represent actual geologic, mining, or economic situations. The hypothetical deposits were constructed to serve the purposes of this study.

The phosphate matrix was assumed to be 20 ft thick and lying beneath either 50, 100, 150, or 230 ft of overburden. The 50 ft of overburden immediately above the phosphate matrix was assumed to contain consolidated carbonate beds and semiconsolidated materials. The upper portion of the overburden contained unconsolidated sand, shell fragments, and clay. The reserves were sufficient to support 20-yr mine lives at production rates of 1.6, 3.3, or 5.0 million short tons of product per year.[4]

The deposits were assumed to be laterally extensive and consistent in quality, bed thickness, and depth. Such deposits are known to exist in parts of northeastern Florida at depths of 200 to 300 ft. Basic deposit assumptions are summarized in appendix A along with mine and mill operating parameters.

BOREHOLE MINING SYSTEM

Borehole mining is a method of recovering phosphate matrix without the removal of overburden. With the proposed borehole mining system, a borehole mining tool is lowered to the phosphate horizon through a predrilled, steel-cased borehole. A rotating water jet on the tool disintegrates the phosphate matrix while a jet pump at the lower end of the tool pumps the resulting slurry to the surface. The slurry is then transported to a beneficiation plant by pipeline. The resulting cavity is backfilled with waste material pumped back from the plant. Figure 1 illustrates a prototype borehole mining unit. Mining unit specifications and operating parameters are summarized in appendix A.

The borehole mining tool is composed of mining, standard, and Kelly sections. The mining section, which houses the cutting jet and jet pump, operates within the phosphate horizon. Standard sections contain the pipes that deliver water and air down to the mining section and carry slurry up to the surface. A Kelly section with a three-passage swivel directs the water, air, and slurry flow through the top standard section. All sections are approximately 20 ft long and 8 in. in diameter. The overall length of the tool can be adjusted by the addition or removal of standard sections, which are installed between the Kelly and mining sections.

[4]Production values are rounded for text reporting purposes. Precise production values used in cost calculations are 1,666,590, 3,333,180, and 5,000,135 short tons of product per year.

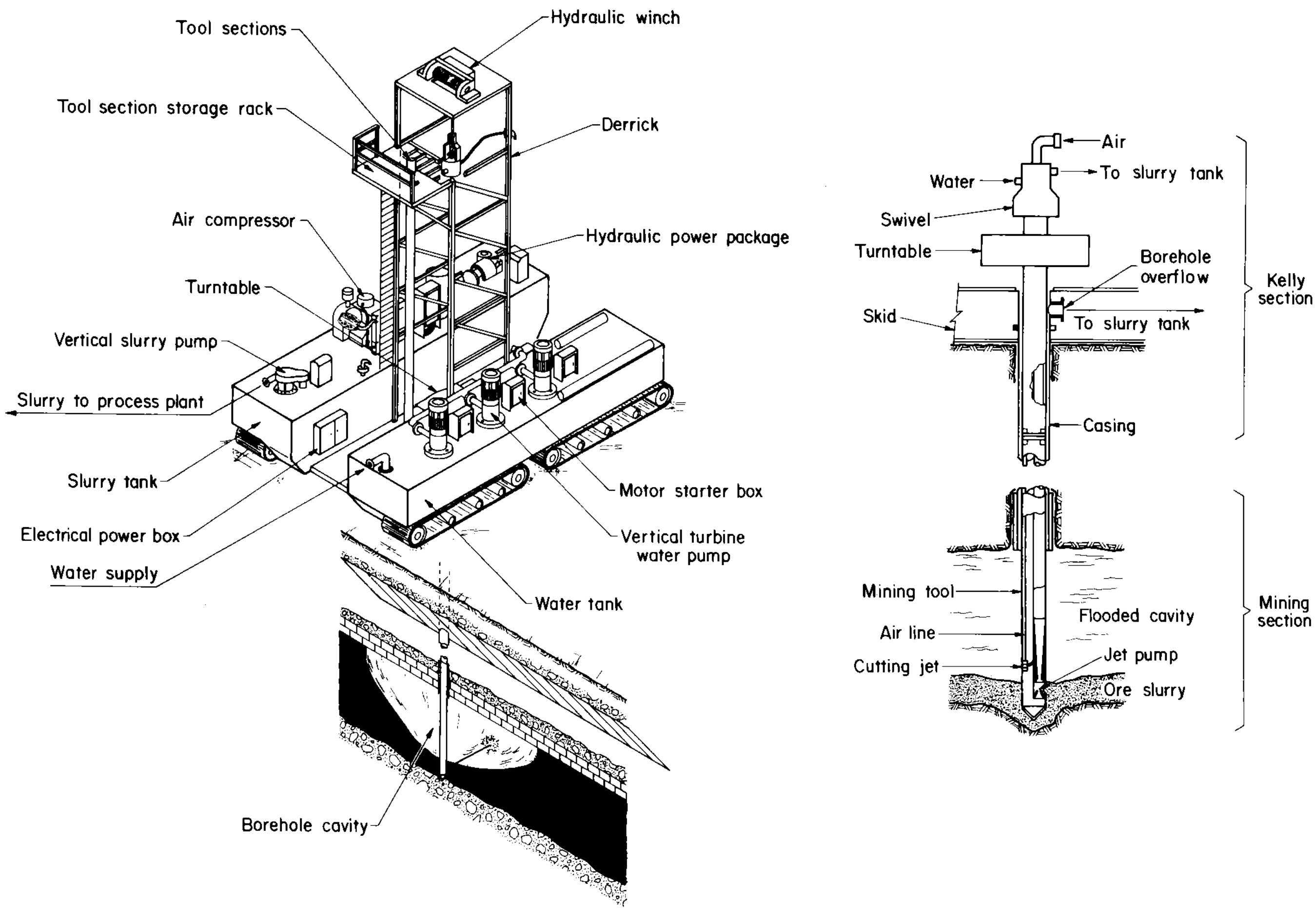

FIGURE 1. - Prototype borehole mining system.
(Courtesy Flow Industries, Inc.)

Operations for borehole mining include site preparation, borehole drilling, equipment set up, mining, backfilling, and reclamation. Each deposit will require site-specific mining procedures to maximize matrix recovery.

During site preparation, bulldozers clear vegetation, level the mining areas, and establish access roads. The borehole drilling locations and sequence of mining the borehole cavities are then marked by a survey crew.

Drill rigs, casing trucks, and a forklift truck are used to drill and case the production boreholes. Holes are drilled to the bottom of the matrix and cased from the top of the ore horizon to the surface. The prototype borehole mining tool described in this study requires a 12-in-diameter cased borehole. A tight fit between the casing and competent strata above the matrix would be established through the use of mechanical or cement seals or expandable packing devices. This would prevent water from being forced into the annulus between the casing and the drill-hole wall and eroding the cavity roof.

Borehole drilling is conducted on a staggered grid pattern. Mining on a staggered grid pattern permits greater matrix recovery than mining on a square pattern while maintaining the same minimum spacing between boreholes. A 70-ft spacing between boreholes would effect a final barrier of 10 ft between mined-out cavities. Barriers must be maintained so that phosphate slurry is not washed into previously mined cavities. Mining recovery is estimated to be 66.6 pct. Future testing may demonstrate that mining recovery may be increased by modifying the shape of cavities or reducing the cavity spacing.

The borehole mining unit, consisting of the mining tool, derrick, pumps, and remote controls, mounted on a crawler base, is positioned over a cased borehole. The mining tool components are bolted together and lowered to the phosphate horizon. A hydraulic winch attached to the top of the derrick lowers and raises the mining tool.

Pumps and compressors on the mining unit deliver water and air through the Kelly and standard sections to the cutting jet and the jet pump. A single cutting jet operates at 1,200 psi to disintegrate the phosphate matrix and form a slurry. Air is directed out of the cutting jet nozzle creating a shield that improves the jet's penetration through the flooded cavity and increases cutting distance. The cutting jet slides vertically within the mining tool to reach matrix from the base to the roof of the phosphate horizon. A turntable on the surface rotates the tool 360° during mining. Slurry flows to the jet pump intakes at the lower end of the mining section and is pumped to the surface. At the surface, the slurry is transported to the beneficiation plant by pipeline.

Matrix surrounding the cavity may slough in toward the mining tool as slurry is removed. Material would lie at an undetermined angle of repose from the bottom of the cavity near the jet pump to the outer perimeter of the cavity. The final cavity would be bowl-shaped with an average radius of 30 ft.

Application of the borehole mining tool would not be limited by depth. The higher ground water pressure associated with a deeper deposit would assist in the pumping of slurry to the surface. Minor adjustments of pumping power would be required to overcome the additional friction between the slurry and the standard section pipeline when mining depth is increased.

Most of the water used in mining, slurry transportation, and beneficiation would be recycled. A small portion of the water used would be lost owing to evaporation. The borehole cavities would receive ground water inflow to partially balance water loss in the other parts of the system. Only small quantities of deep-well, makeup water would be needed.

After approximately 50 h of mining, the solids content of the slurry drops, indicating that the borehole cavity is mined out. The borehole tool is then withdrawn from the hole. Sections are separated and stored on a vertical rack. The mining unit is then moved to the next borehole location and the tool is again lowered to the phosphate bed. Total time required to withdraw the tool, move, and lower the tool down the next borehole varies from 3 to 5 h depending upon hole depth.

One person operates each mining unit with extra personnel available to withdraw the tool and help move it between boreholes. A maintenance crew performs all maintenance and repair work and keeps a stock of spare parts and supplies on hand. Supervisors manage the mining, plan the moves, monitor progress, and keep the operation fully staffed and in production. One supervisor would be required to manage six direct labor employees.

Clay and sand tailings would be generated during the beneficiation process. Dewatered clay and sand tailings are combined and pumped from the beneficiation plant to the mining area where a backfill rig refills the borehole cavities (3). Backfilling reduces or eliminates the possibility of surface subsidence and provides a means of disposing of both the clay and sands.

The higher density clay-sand mixture, when introduced below clear water, does not mix with overlying water. The disposal of the wastes into the borehole cavity displaces relatively clear ground water, which would subsequently be recovered from the top of the borehole and recirculated for plant use.

In the final stages of backfilling, the steel casing is pulled from the hole and reused. The Florida Department of Environmental Regulations currently requires concrete sealing of the borehole with the steel casing in place. The department has waived this requirement for future borehole mining experiments.

Reclamation following borehole mining would be minimal when compared with that required for surface mining operations. Minor regrading and scarifying would be done by bulldozers, followed by revegetation with natural grasses and shrubs. As in conventional surface mining, approximately three growing seasons of reclamation area maintenance would be required to assure successful revegetation.

The capacity of the proposed borehole mining unit is assumed to be 50 short tons of matrix per hour. Higher production can be achieved by increasing the number of mining units. Economies of scale do not apply to this system because different capacity tools have not been developed.

GEOLOGIC CONSIDERATIONS

The phosphate industry in the Southeast is currently surface mining phosphate deposits with overburden thicknesses of up to 110 ft. Such overburden consists of unconsolidated sand and clay with no competent beds. Initial tests conducted for the Bureau indicated that for the successful application of borehole mining, a relatively competent rock bed must immediately overlie the phosphate matrix. A competent bed prevents contamination of the matrix with sand and clay overburden that would otherwise cave into the borehole cavities.

Primary phosphate deposits, those with no secondary reworking, facilitate mining by the borehole method. Primary deposits are very uniform in occurrence, quality, and thickness, which makes exploration data easier to interpret and mining easier to plan. This results in less exploration drilling. Since primary deposits contain only minor quantities of pebble, a more pumpable slurry results and the performance of the slurry pumping system is improved.

While conclusive experiments have not been run, clay lenses within the matrix are believed to break up and then fall to the cavity floor as the matrix is mined; the larger fragments would then accumulate on the cavity floor. This action would reduce the actual clay content of the material elevated to the surface and improve the overall phosphate grade of the recovered matrix.

The grain size of the matrix particles and other primary depositional features of the bed may influence the shape of the borehole cavities. Owing to depositional variations, borehole cavities may assume irregular, noncircular shapes.

CONVENTIONAL MINING SYSTEMS

The hypothetical deposits described in this study can also be recovered by conventional mining technology. The surface mining system employed depends upon the thickness and character of the overburden. Various overburden situations are addressed in three generalized cases. A cross section illustrating the three case situations is shown in figure 2.

Site preparation work would be required in all three cases. Clearing vegetation, building access roads, and leveling mining areas would be accomplished by bulldozers.

In case 1, the 20-ft phosphate bed is overlain by 50 ft of interbedded carbonates, sands, and clays. A dragline

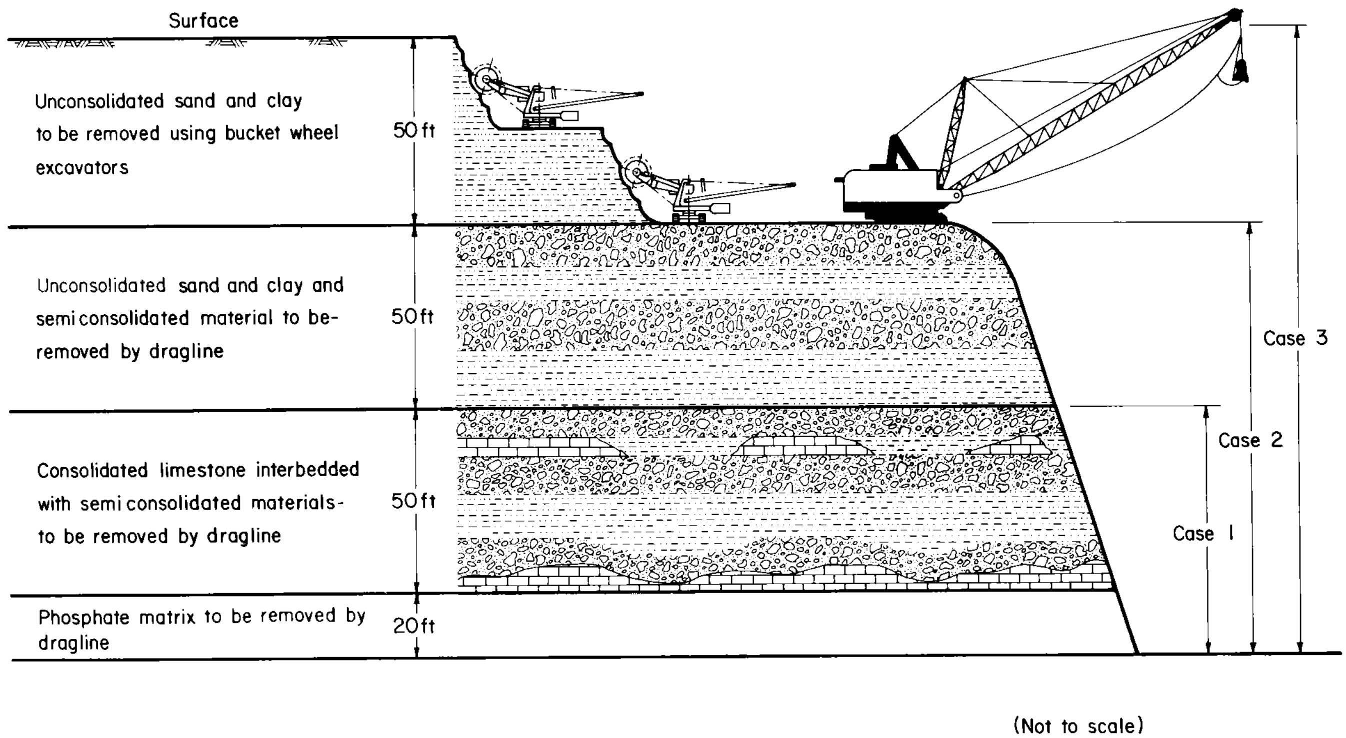

FIGURE 2. - Conventional mining systems.

removes this overburden and casts it into a previously mined cut to expose the phosphate matrix. The same dragline excavates the matrix and transfers it to a slurry pit. In the slurry pit, water jets break up the friable ore, creating a slurry that is pumped to a beneficiation plant.

For case 2, an additional 50 ft of semiconsolidated overburden lies above the case 1 overburden, resulting in a total overburden depth of 100 ft. A dragline operating from the surface removes overburden and mines the matrix as described in case 1.

For case 3, 50 ft of unconsolidated sand and clay lies above the case 2 overburden, resulting in a total overburden depth of 150 ft. The top 50 ft of overburden is stripped by two bucket wheel excavators, conveyed around the pit, and spread over mined out areas by stacker-reclaimers. Removal of the semiconsolidated overburden and phosphate matrix recovery proceeds as described in case 1.

Reclamation involves casting overburden into mined-out cuts along with waste material from the beneficiation plant. A mixture of thickened clay slimes and sand tailings from the beneficiation plant is transported by pipeline to the mining area and backfilled into mined-out cuts. Draglines or dozers cover the waste with overburden material. Reasonable ground stability is expected since the amount of dewatered slimes and tailings is small compared with the amount of overburden cover. Topsoil is spread over the regraded areas. The reclaimed land is suitable for agriculture or pasture. The ground surface would be stable enough to support most residential and industrial construction.

Each case was evaluated at various production rates. Economies of scale are anticipated since draglines and bucket wheel excavators are available in different sizes. Conventional mining operating parameters are summarized in appendix A.

BENEFICIATION SYSTEM

The beneficiation processes for the primary phosphate matrix produced by borehole mining and conventional mining are identical. The operating parameters and recovery rates for beneficiation are based upon metallurgical tests.

The major steps of the beneficiation process are washing and flotation. Washing removes the clay fraction transported with the matrix. A double-stage flotation circuit upgrades the washed feed. The grain size of feed is consistent, with 95 pct in the minus 35- to plus 200-mesh range. Owing to the grain size and high feed grade, 92 pct phosphate recovery is achieved in the double-float circuit. Since some phosphate is lost in the washing circuit, an overall phosphate recovery of 85.7 pct is expected. The resulting product output tonnage equals about 46 pct of matrix input. The general operating parameters for the beneficiation system are summarized in appendix A.

Waste clays produced during washing are thickened in clay holding ponds constructed near the plant. Advanced dewatering methods are employed to minimize the pond retention time. It is assumed that 1 yr of clay settling capacity would be required.

Thickened clay slimes are combined with sand tailings from flotation, pumped to the mining areas, and backfilled into mined-out cuts or borehole cavities.

ENVIRONMENTAL CONSIDERATIONS

Surface mining of phosphate has been occurring in central Florida for more than 90 yr. Very rugged landscapes and large above-grade clay dewatering ponds mark the locations of unreclaimed surface mining operations, and regulations now require the reclamation of surface mining areas for agricultural and recreational uses.

Borehole mining may become a more environmentally acceptable alternative method for recovering phosphate, since commercial application of the borehole mining system eliminates the need for the removal of overburden material. Actual land disturbance is limited to clearing of vegetation and minor leveling of mining areas. The need to backfill and grade spoil piles, and the associated costs, are eliminated. Site cleanup and revegetation are the only reclamation procedures required.

Phosphate beneficiation yields sand tailings and water-retentive clay waste (clay) materials. The clay in central Florida, prior to dewatering, occupies between 1.25 and 2.0 times more volume than the unmined phosphate matrix (5-6). The resulting extra volume of waste material is currently stored in above-grade clay dewatering ponds for extended periods of time.

Traditional methods of disposing of wastes, especially clays, are now being discouraged. The Florida Department of Environmental Regulation (2) currently takes the position that because the "storage of waste clays for long periods of time interferes with expeditious reclamation and above grade storage of clays takes otherwise useful land out of production and raises potential health and safety problems, below grade storage and rapid reclamation techniques are encouraged." In the future, surface mining operations will employ additional mechanical and chemical methods to reduce the clay volume, mix the clay with sand tailings, and backfill the waste into mined-out cuts. In borehole mining the waste is backfilled into mined-out cavities. Long-term above-grade waste storage is thus avoided.

Water used in borehole mining and beneficiation is recirculated within the system. A large quantity of water is made available through the clay dewatering process. Ground water, infiltrating borehole cavities at a slow rate, would be pumped from the cavities in the slurry. Ground water forced out of the cavity during backfilling would be pumped to the beneficiation plant for use. It is assumed that sufficient water is generated during clay dewatering and mining for use throughout the system.

Earlier studies indicated that borehole mining has not affected local water tables (4). To insure that the aquifers remained undamaged, the experimental boreholes in St. Johns County were sealed. The steel casings were left in place and the boreholes were sealed with concrete from the top of the cavity to the surface. If this procedure is required in a large-scale operation, operating costs would be prohibitively high. The cooperation of government agencies would be required to reevaluate the need for sealing and develop lower cost alternatives.

Significant controversy exists concerning the health hazard associated with radon levels on reclaimed phosphate lands following surface mining. The borehole mining system would minimize this exposure. Since the overburden is not disturbed, a significant earth buffer would remain intact above unrecovered uranium-enriched phosphate strata between boreholes and beneficiation wastes that are backfilled into mined-out borehole cavities.

ECONOMIC EVALUATION

An economic evaluation of borehole and conventional mining systems at selected production rates of 1.6, 3.3, and 5.0 million short tons of product per year[5] was conducted at overburden depths of 50, 100, 150, and 230 ft for the borehole system, and 50, 100, and 150 ft for the conventional system. The 230-ft overburden depth represents mining conditions in northern Florida and the depth for which Flow Industries, Inc., and Agrico Chemical Co. provided borehole mining data. Mine and mill capital and operating costs were estimated for these production rates and deposit depths.

Discounted cash flow analyses were used to generate rates of return and product prices based on 20-yr project lives (1). Details of the analyses are given in appendix E. The results of the economic evaluations of the borehole mining system are presented in table 1 and those of the conventional mining system are presented

[5]See footnote 4.

TABLE 1. - Borehole mining system economic evaluation results

Overburden, ft	Capital costs		Operating costs[1]		Rate of return,[2] pct	Price[1]	
	Mine	Mill	Mine	Mill		Break even	20-pct rate of return
1,666,590 SHORT TONS OF PRODUCT PER YEAR							
50..........	$45,598,000	$36,202,000	$11.64	$1.70	19.32	$16.26	$30.74
100..........	46,094,000	36,202,000	12.40	1.70	18.61	17.08	31.51
150..........	46,591,000	36,202,000	13.17	1.70	17.89	17.89	32.28
230..........	47,385,000	36,202,000	14.39	1.70	16.72	19.20	33.51
3,333,180 SHORT TONS OF PRODUCT PER YEAR							
50..........	$91,357,000	$55,122,000	$11.83	$1.59	20.91	$16.13	$29.08
100..........	92,350,000	55,122,000	12.60	1.59	20.15	16.96	29.85
150..........	93,343,000	55,122,000	13.36	1.59	19.39	17.77	30.61
230..........	94,932,000	55,122,000	14.59	1.59	18.13	19.08	31.85
5,000,135 SHORT TONS OF PRODUCT PER YEAR							
50..........	$137,151,000	$70,518,000	$11.90	$1.54	21.77	$16.06	$28.28
100..........	138,613,000	70,518,000	12.67	1.54	21.01	16.86	29.03
150..........	140,103,000	70,518,000	13.43	1.54	20.22	17.67	29.79
230..........	142,486,000	70,518,000	14.66	1.54	18.92	18.98	31.02

[1]Per short ton of phosphate rock product.
[2]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.

TABLE 2. - Conventional mining system economic evaluation results

Overburden, ft	Capital costs		Operating costs[1]		Rate of return,[2] pct	Price[1]	
	Mine	Mill	Mine	Mill		Break even	20-pct rate of return
1,666,590 SHORT TONS OF PRODUCT PER YEAR							
50..........	$59,161,000	$36,202,000	$5.09	$1.70	22.70	$10.18	$26.70
100..........	75,178,000	36,202,000	6.40	1.70	19.87	12.19	30.17
150..........	126,053,000	36,202,000	12.60	1.70	11.19	20.13	43.04
3,333,180 SHORT TONS OF PRODUCT PER YEAR							
50..........	$113,733,000	$55,122,000	$4.39	$1.59	25.38	$8.98	$23.87
100..........	128,057,000	55,122,000	5.06	1.59	23.86	9.94	25.51
150..........	210,129,000	55,122,000	9.40	1.59	16.05	15.66	35.29
5,000,135 SHORT TONS OF PRODUCT PER YEAR							
50..........	$168,575,000	$70,518,000	$3.75	$1.54	26.96	$8.04	$22.32
100..........	179,023,000	70,518,000	4.64	1.54	25.74	9.14	23.63
150..........	287,725,000	70,518,000	8.24	1.54	18.38	13.95	32.05

[1]Per short ton of phosphate rock product.
[2]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.

in table 2. Mill capital and operating costs are also summarized in tables 1 and 2. Operating costs do not include depreciation, depletion, and other noncash flow items.

The cost of initial deposit exploration is not included in capital cost estimations. Development of a uniform phosphate resource over a broad area usually involves exploratory drilling of low density. Initial exploration cost for a particular tract is therefore small relative to other capital investments and would be the same for both systems. Premining control drilling is included in the borehole and conventional mining operating costs.

Legal, environmental impact statement, permitting, and interest costs are not included in the mine or mill capital cost estimations. Salvage values were estimated as 10 pct of the initial capital investments for plant and equipment. Straight-line depreciation of plant and equipment was employed.

Working capital for the borehole, conventional, and beneficiation systems equals 90 days operating cost.

All cost estimates are adjusted to January 1981 dollars using Bureau of Labor Statistics cost indexes. Economic comparisons of the mining systems are illustrated in figures 3, 4, and 5.

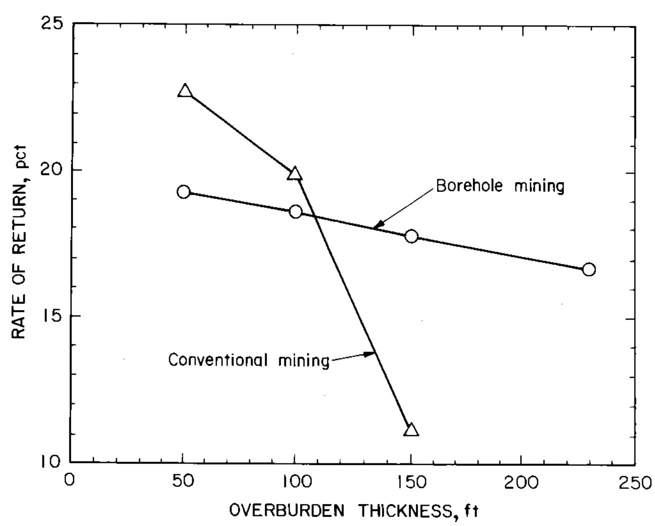

FIGURE 3. - Economic comparison–borehole mining versus conventional mining at 1.6 million short tons of product per year. Discounted cash flow rate of return at $30 per short ton of phosphate rock product.

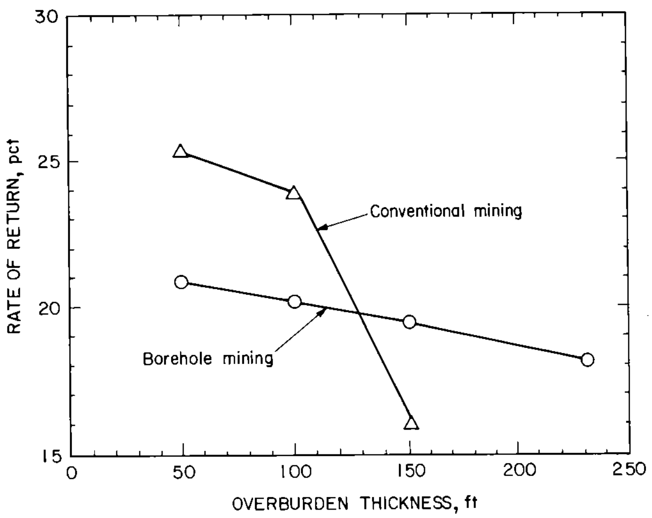

FIGURE 4. - Economic comparison—borehole mining versus conventional mining at 3.3 million short tons of product per year. Discounted cash flow rate of return at $30 per short ton of phosphate rock product.

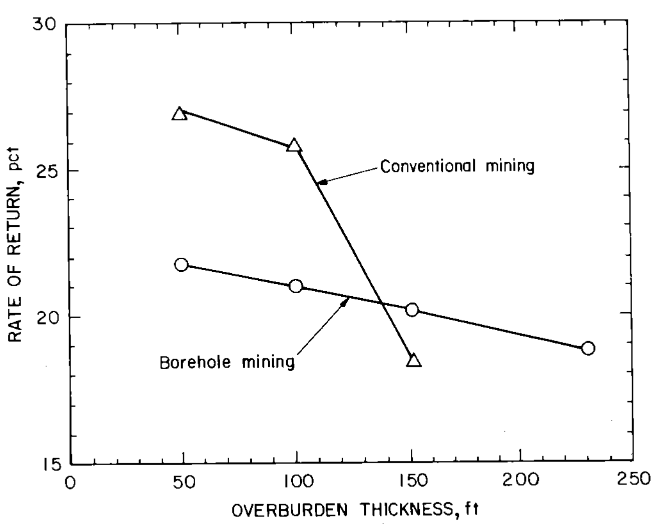

FIGURE 5. - Economic comparison—borehole mining versus conventional mining at 5.0 million short tons of product per year. Discounted cash flow rate of return at $30 per short ton of phosphate rock product.

BOREHOLE MINING CAPITAL COST

Capital costs for the borehole mining system include land acquisition, the borehole mining units, miscellaneous mining equipment, and working capital. Details of the borehole mining capital cost are presented in appendix B.

Land acquisition costs are based on an estimated cost of $1 per short ton of product recovered over the 20-yr life of the operation, thereby relating land value directly to the value of the recoverable phosphate.

When commercially available, a prototype borehole mining unit, capable of operating at 230 ft of overburden, is estimated to cost $700,000. This cost represents a fixed cost for the surface unit, Kelly, and mining sections and a variable cost for the standard sections. The standard section length and cost vary with the mining depth. The total borehole mining unit cost is obtained by multiplying the single unit cost, based upon deposit depth, by the number of units required. The number of units required is based upon the mine capacity, a mining rate of 50 short tons per hour, a utilization level of 24 h per day, and the effective availability of the mining unit, which varies with deposit depth. A 10-pct contingency cost is then added to the total mining unit capital cost. Borehole mining units are not replaced during the life of the mine and are depreciated over the first 15 yr of operation.

The miscellaneous mining equipment cost is based upon an estimated cost of $40,000 per unit multiplied by the number of units. A 10-pct contingency factor is then added. Miscellaneous mining equipment is replaced after 10 yr of operation. Costs are depreciated over the first 8 yr of use.

BOREHOLE MINING OPERATING COST

Operating cost for the borehole mining system is composed of 14 cost elements and details are present in appendix B.

Site preparation cost is estimated at $2,326 per acre. The acreage required for each operation is based upon the operating schedule, matrix density, and the mining recovery.

Drilling, casing, and sealing cost includes premining control drilling, borehole drilling, and borehole casing and sealing costs. Control drilling is based upon a hole density of 0.4 hole per acre, deposit depth, and an estimated average cost of $3.50 per foot for core drilling and gamma ray logging.

The operating labor cost is based on an estimated labor rate of $12 per hour, as applied to the number of employees and the operating schedule.

The annual support and maintenance labor costs are estimated to be 80 and 25 pct, respectively, of the annual operating labor cost.

Supervisory labor costs are estimated as a percentage of the total annual operating labor, support labor, and maintenance labor costs. The percentages used at the 1.6, 3.3, and 5.0 million short ton per year production rates are 20, 15, and 10 pct, respectively.

Payroll benefits and payroll overhead cost elements are estimated as 30 and 40 pct, respectively, of the total of all four labor cost elements.

The prototype unit is estimated to require power for the cutting jet, slurry pump, and other smaller pumps, for a total of 2,400 bhp which includes a 300-bhp variance with mining depth. The estimated annual power cost equals $580,682 per unit plus a variable cost per unit of $332 per foot of total mining depth.

The annual maintenance supply cost is estimated at $30,000 per unit, operating on a 330 day per year schedule. This cost is adjusted to the 365 day per year schedule and multiplied by the number of units required.

The health and safety cost is based on an annual cost estimate of $190,000 per year for 10 units operating for 330 days per year. This cost is adjusted to the required number of units and proposed operating schedule.

Site reclamation cost, including cavity backfilling, is based on an estimate of $1.50 per short ton of material backfilled.

The slurry transportation cost is based on an estimated cost of $0.18 per short ton-mile, multiplied by the tonnage of ore and waste transported and by the average transportation distance.

The fixed costs attributed to mining are estimated to be 85 pct of the total annual mineral severance tax, local taxes, and insurance cost. Severance tax, after ad valorem tax credit and reclamation rebate, is estimated at $1.21 per short ton of product. Local taxes and insurance are estimated at $0.58 per short ton of product.

The operating cost, per short ton of product, is then obtained by dividing the total annual operating cost by the annual product tonnage.

CONVENTIONAL MINING CAPITAL COST

Capital costs for the conventional mining system included land acquisition, mine equipment, draglines and bucket wheel excavators, and working capital. Details of the conventional mining capital cost are presented in appendix C.

Land acquisition costs are equal to the land acquisition costs for the borehole mining system at the same production rate. Although mining recovery is higher for the conventional system, and less acreage is required, the costs are equivalent since they are based upon $1 per short ton of product recovered over the life of the mine.

Mine equipment and dragline and bucket wheel excavator costs are based on cost estimates developed by industry and published sources. Costing models were followed for all calculations involving draglines and related expenses (7). At

150-ft overburden depths, where bucket wheel excavators are required, separate additional capital costs are developed.

Mine equipment costs include the support equipment for the dragline and bucket wheel excavation systems. Some elements of the initial base mine capital cost estimates required adjusting according to the following formula:

$$\text{New mine capital cost} = \text{Base mine capital cost} \times \left[\frac{\text{New mine capacity}}{\text{Base mine capacity}}\right]^{0.7}.$$

This scaling formula is based upon the assumption that capital costs are exponentially related to production capacity.

Dragline capital costs are based upon the number of draglines required, the dragline sizes, and equipment manufacturer's suggested costs. The proposed overburden depths and production rates determined the quantity and size of the equipment.

The total bucket wheel system cost is based upon an estimated system cost of $108,535,540 for moving 28.7 million bank cubic yards of overburden per year. This cost is scaled to the proposed production rates using the 0.7 exponential scaling formula. Costs of the bucket wheel excavators, conveyor systems, and stacker reclaimers are estimated to be 90 pct of the total bucket wheel system cost and are allocated to the dragline and bucket wheel excavator cost category. The remaining 10 pct is for support equipment and is attributed to the mine equipment cost category.

Items included under mine equipment cost are replaced after the first 10 yr of production. They are depreciated over the first 8 yr of use. Draglines and bucket wheel excavators are not replaced during the 20-yr production periods. They are depreciated over the first 15 yr of operation.

CONVENTIONAL MINING OPERATING COST

Operating costs for the conventional mining systems are composed of 18 cost elements and details are presented in appendix C. The estimated dragline operating costs and related expenses were calculated using cost models developed by Zellars-Williams, Inc. (7). The bucket wheel excavator system annual operating costs are based upon known system costs scaled to the proposed production rates and other factors.

The two most important controlling factors in the cost evaluation are the phosphate reserve grade and characteristics and the mine capacity. Matrix pumping distances and mine recovery are examples of miscellaneous factors considered in the cost model.

The power cost element is composed of dragline, slurry pit, and pumping power requirements. A power cost rate of $0.0416 per kilowatt hour is used to obtain the total annual power cost.

The outside services cost element is composed of mine site preparation costs plus reclamation costs. Mine site preparation and reclamation costs are estimated at $708 and $2,500 per acre, respectively.

Matrix pipeline cost is estimated at $34 per foot. The cost of premining control drilling, gamma ray logging, and core analysis is estimated at $3.50 per foot. A drilling density of 0.4 hole per acre is used.

Severance tax, after ad valorem tax credit and reclamation rebate, is estimated at $1.21 per short ton of product. Local taxes and insurance are estimated at $0.54 per short ton of product plus a 4-pct sales tax.

The operating cost, per short ton of product, is then obtained by dividing the total annual operating cost by the annual product tonnage.

BENEFICIATION SYSTEM CAPITAL COST

Capital costs for the beneficiation system included mill plant capital and working capital. Details are presented in appendix D. At each production rate, the beneficiation processes and associated capital costs are equal for the borehole and conventional mining systems. Mill plant capital cost is estimated at $35,500,000 for a 1.6 million short ton per year plant. This cost is scaled to the other production rates using an exponential scaling factor of 0.6 in the following formula:

$$\text{New mill capital cost} = \text{Base mill capital cost} \times \left[\frac{\text{New mill capacity}}{\text{Base mill capacity}}\right]^{0.6}.$$

BENEFICIATION SYSTEM OPERATING COST

Operating costs for the beneficiation system included power and labor, reagents, and fixed costs. Details are presented in appendix D. At each production rate, the beneficiation processes and associated operating costs are equal for the borehole and conventional mining systems. Mill operating cost for power, labor, reagents, and depreciation is estimated at $2.50 per short ton of product for a plant producing 1.6 million short tons per year. This estimate is reduced by the plant depreciation cost, with a final estimate being $1.43 per short ton of product (for power, labor, and reagents).

Reagents are estimated to be 60 pct of this cost, while the power and labor cost category is estimated at 40 pct. The power and labor cost element is scaled to adjust for other proposed production rates. The scaling method used is based upon the assumption that operating cost is exponentially related to the production capacity of the mill. The formula used is

$$\text{New mill power and labor cost} = \text{Base mill power and labor cost} \times \left[\frac{\text{Base mill capacity}}{\text{New mill capacity}}\right]^{0.3}.$$

The fixed costs attributed to beneficiation are estimated to be 15 pct of the total annual mineral severance tax, local taxes, and insurance cost. Severance tax, after ad valorem tax credit and reclamation rebate, is estimated at $1.21 per short ton of product. Local taxes and insurance are estimated at $0.58 per short ton.

CONCLUSIONS

Based on the economic evaluation of the borehole and conventional mining systems, borehole mining systems are economically superior for the recovery of deep bedded phosphate deposits. However, the recovery of shallow phosphate deposits by conventional mining is economically more attractive than by borehole mining.

Conventional surface mining with 50 and 100 ft of overburden is more economical (i.e., has a higher rate of return) than borehole mining at all three production rates examined. At 150 ft of overburden, borehole mining is economically superior at all production rates. Only the borehole mining system was evaluated at a 230-ft overburden thickness. The economic attractiveness (as measured by rate of return) of the conventional mining systems falls rapidly between 100 and 150 ft of overburden owing to significantly higher capital and operating costs. By extrapolating the data, rate of return for conventional mining with 230 ft of overburden is expected to be prohibitively low, perhaps negative, at a product price of $30 per short ton. The borehole mining system maintains a high level of economic attractiveness at 150 and 230 ft of overburden.

Conventional phosphate mines in Florida typically achieve rates of return between 15 and 20 pct. The operations evaluated in this study attain comparable levels of profitability except for low production conventional mining with 150 ft of overburden.

Borehole mining is environmentally more desirable for recovering phosphate deposits than conventional surface mining alternatives. The surface area disturbed at any time during borehole mining is minimal. Borehole mining recovers the phosphate matrix without disturbing the material overlying the ore. Reclamation work required to restore the surface after borehole mining is limited to minor regrading and revegetation.

The borehole mining system is an economically and environmentally attractive method of recovering phosphate under certain geologic conditions. With the increasing need to mine deeper phosphate deposits, development of borehole mining technology should progress and in the future may supply a significant share of the demand for phosphate.

SUGGESTIONS FOR FURTHER INVESTIGATION

1. Exploration or evaluation of areas where borehole mining can be applied to recover phosphate.

- Delineate phosphate potential in areas where borehole mining can be applied.

- Assess the potential of applying borehole mining to offshore phosphate deposits.

2. Testing the application of borehole mining under various overburden conditions.

- Determine cavity roof competence needed to prevent cavity collapse.

- Test application of borehole mining methods in areas with no relatively competent overburden.

3. Improve mechanical efficiency of borehole mining equipment.

- Examine various mining tool diameters to find the optimum diameter tool and borehole.

- Improve maneuverability of the water jet nozzle to increase mobility and cutting radius.

- Redesign mining tool to increase unit production and maximize mining recovery. Evaluate possible economies of scale if production rate per unit exceeds 50 short tons of matrix per hour.

- Determine possible borehole cavity shapes, sizes, and spacings; estimate associated mining recovery rates.

- Evaluate to what extent a seal is required between the casing and top of the ore zone.

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APPENDIX A.--MINING AND BENEFICIATION PARAMETERS

Basic deposit assumptions

Matrix thickness................ft..	20
Matrix density..............lb/ft^3..	88
Average overburden density..lb/ft^3..	88
Matrix grade, pct:	
Bone phosphate of lime[1]...........	36.25
P_2O_5............................	16.59
Pebble content of matrix.......pct..	0
Clay content of matrix.........pct..	25
Matrix "X"[2]...................yd^3..	1.84

[1]1 pct BPL = 0.458 pct P_2O_5.
[2]Matrix per short ton of product.

General operating parameters

Recovery, pct:	
Washing...........................	93.1
Flotation.........................	92.0
Overall beneficiation.............	85.7
Product grade, pct:	
Bone phosphate of lime[1]...........	68.00
P_2O_5............................	31.14
Operating shifts per day............	3
Utilization level................h..	24
Operating days per year.............	365
Mine life.......................yr..	20

[1]1 pct BPL = 0.458 pct P_2O_5.

Borehole mining unit--Specifications and approximate operating parameters

Average unit mining rate....tph..	50
Tool rotation rate..........rpm..	10
Mining tool diameter.........in..	8
Standard section length......ft..	20
Cutting jet:	
Flow rate.................gpm..	1,000
Pressure..................psi..	1,200
Power.....................hp..	1,000
Electric motors (500 hp, 2,300 V ac)..................	2
Jet pump:	
Flow rate.................gpm..	500
Pressure..................psi..	1,200
Power (for 250-ft mining depth)...................hp..	500
Electric motor (500 hp)........	1
Air compressor:	
Flow rate................scfm..	1,500
Pressure..................psi..	250
Power.....................hp..	400
Electric motor (400 hp, 2,300 V ac)..................	1
Slurry pump:	
Discharge flow rate.......gpm..	1,600
Power.....................hp..	150
Electric motor (150 hp, 2,300 V ac)..................	1
Slurry tank capacity........gal..	500
Water tank capacity.........gal..	2,000
Hydraulic power package......hp..	200
Hydraulic electric motor (200 hp, 2,300 V ac.....................	1
Size of mining unit..........ft..	10 by 10 by 30
Approximate unit weight (tanks empty, no sections).........lb..	150,000
Average cavity radius........ft..	30
Cavity separation............ft..	10
Borehole separation..........ft..	70
Operating factor............pct..	90
Move and setup................h..	3-5

Borehole and conventional mining parameters at three production rates

Annual product output, short tons..............	1,666,590	3,333,180	5,000,135
Borehole mining parameters:			
Daily product output.............short tons..	4,566	9,132	13,698
Daily matrix production................do....	10,000	20,000	30,000
Mining units...............................	10	20	30
Area mined per year...................acres..	143	286	429
Total area mined in 20 yr.............do....	2,860	5,720	8,580
Mining recovery........................pct..	66.6	66.6	66.6
Conventional mining parameters:			
Daily product output.............short tons..	4,566	9,132	13,698
Daily matrix production................do....	10,000	20,000	30,000
Number of draglines and capacity at--			
50-ft overburden..........................	1, 35 yd^3	2, 35 yd^3	2, 52 yd^3
100-ft overburden.........................	2, 31 yd^3	3, 41 yd^3	4, 46 yd^3
150-ft overburden[1]........................	2, 31 yd^3	3, 41 yd^3	4, 46 yd^3
Area mined per year...................acres..	112	224	336
Total area mined in 20 yr.............do....	2,240	4,480	6,720
Mining recovery........................pct..	85.0	85.0	85.0

[1]Bucket wheel excavators used also.

APPENDIX B.--BOREHOLE MINING SYSTEM CAPITAL AND OPERATING COSTS

TABLE B-1. - Estimated capital requirements, borehole mining system

Overburden, ft	50	100	150	230
1,666,590 SHORT TONS OF PRODUCT PER YEAR				
Acquisition[1]	$33,332,000	$33,332,000	$33,332,000	$33,332,000
10 mining units	7,047,000	7,228,000	7,410,000	7,700,000
Miscellaneous mining equipment	440,000	440,000	440,000	440,000
Working capital[2]	4,779,000	5,094,000	5,409,000	5,913,000
Total	45,598,000	46,094,000	46,591,000	47,385,000
3,333,180 SHORT TONS OF PRODUCT PER YEAR				
Acquisition[1]	$66,664,000	$66,664,000	$66,664,000	$66,664,000
20 mining units	14,093,000	14,456,000	14,819,000	15,400,000
Miscellaneous mining equipment	880,000	880,000	880,000	880,000
Working capital[2]	9,720,000	10,350,000	10,980,000	11,988,000
Total	91,357,000	92,350,000	93,343,000	94,932,000
5,000,135 SHORT TONS OF PRODUCT PER YEAR				
Acquisition[1]	$100,003,000	$100,003,000	$100,003,000	$100,003,000
30 mining units	21,140,000	21,684,000	22,229,000	23,100,000
Miscellaneous mining equipment	1,320,000	1,320,000	1,320,000	1,320,000
Working capital[2]	14,688,000	15,606,000	16,551,000	18,063,000
Total	137,151,000	138,613,000	140,103,000	142,486,000

[1]Cost of property required for 20-yr operation.
[2]Working capital equals 90 days' operating cost.

TABLE B-2. - Estimated annual operating costs, borehole mining system

Overburden, ft	50	100	150	230
1,666,590 SHORT TONS OF PRODUCT PER YEAR				
Site preparation	$332,558	$332,558	$332,558	$332,558
Drilling, casing, and sealing	1,558,368	2,668,628	3,778,888	5,555,304
Operating labor	1,051,200	1,051,200	1,051,200	1,051,200
Support labor	840,960	840,960	840,960	840,960
Maintenance labor	262,800	262,800	262,800	262,800
Supervisory labor	430,992	430,992	430,992	430,992
Payroll benefits	775,786	775,786	775,786	775,786
Payroll overhead	1,034,381	1,034,381	1,034,381	1,034,381
Power	6,039,220	6,205,220	6,371,220	6,636,820
Maintenance supplies	331,820	331,820	331,820	331,820
Health and safety	210,152	210,152	210,152	210,152
Site reclamation	2,975,115	2,975,115	2,975,115	2,975,115
Slurry transportation	1,014,014	1,014,014	1,014,014	1,014,014
Fixed costs	2,535,717	2,535,717	2,535,717	2,535,717
Total	19,393,083	20,669,343	21,945,603	23,987,619
3,333,180 SHORT TONS OF PRODUCT PER YEAR				
Site preparation	$665,116	$665,116	$665,116	$665,116
Drilling, casing, and sealing	3,116,736	5,337,256	7,557,776	11,110,608
Operating labor	2,102,400	2,102,400	2,102,400	2,102,400
Support labor	1,681,920	1,681,920	1,681,920	1,681,920
Maintenance labor	525,600	525,600	525,600	525,600
Supervisory labor	646,488	646,488	646,488	646,488
Payroll benefits	1,486,922	1,486,922	1,486,922	1,486,922
Payroll overhead	1,982,563	1,982,563	1,982,563	1,982,563
Power	2,078,440	12,410,440	12,742,440	13,273,640
Maintenance supplies	663,640	663,640	663,640	663,640
Health and safety	420,300	420,300	420,300	420,300
Site reclamation	5,950,230	5,950,230	5,950,230	5,950,230
Slurry transportation	3,042,041	3,042,041	3,042,041	3,042,041
Fixed costs	5,071,433	5,071,433	5,071,433	5,071,433
Total	39,433,829	41,986,349	44,538,869	48,622,901
5,000,135 SHORT TONS OF PRODUCT PER YEAR				
Site preparation	$997,674	$997,674	$997,674	$997,674
Drilling, casing, and sealing	4,675,104	8,005,884	11,336,664	16,665,912
Operating labor	3,153,600	3,153,600	3,153,600	3,153,600
Support labor	2,522,880	2,522,880	2,522,880	2,522,880
Maintenance labor	788,400	788,400	788,400	788,400
Supervisory labor	646,488	646,488	646,488	646,488
Payroll benefits	2,133,410	2,133,410	2,133,410	2,133,410
Payroll overhead	2,844,547	2,844,547	2,844,547	2,844,547
Power	18,117,660	18,615,660	19,113,660	19,910,460
Maintenance supplies	995,460	995,460	995,460	995,460
Health and safety	630,450	630,450	630,450	630,450
Site reclamation	8,924,798	8,924,798	8,924,798	8,924,798
Slurry transportation	5,475,556	5,475,556	5,475,556	5,475,556
Fixed costs	7,607,706	7,607,706	7,607,706	7,607,706
Total	59,513,733	63,342,513	67,171,293	73,297,341

APPENDIX C.--CONVENTIONAL MINING SYSTEM CAPITAL AND OPERATING COSTS

TABLE C-1. - Estimated capital requirements, conventional mining systems

Overburden, ft	50	100	150
1,666,590 SHORT TONS OF PRODUCT PER YEAR			
Acquisition[1]	$33,332,000	$33,332,000	$33,332,000
Mine equipment	14,262,000	22,103,000	26,936,000
Draglines and bucket wheel excavators	9,479,000	17,115,000	60,610,000
Working capital[2]	2,088,000	2,628,000	5,175,000
Total	59,161,000	75,178,000	126,053,000
3,333,180 SHORT TONS OF PRODUCT PER YEAR			
Acquisition[1]	$66,664,000	$66,664,000	$66,664,000
Mining equipment	24,511,000	28,798,000	36,649,000
Draglines and bucket wheel excavators	18,958,000	28,437,000	99,094,000
Working capital[2]	3,600,000	4,158,000	7,722,000
Total	113,733,000	128,057,000	210,129,000
5,000,135 SHORT TONS OF PRODUCT PER YEAR			
Acquisition[1]	$100,003,000	$100,003,000	$100,003,000
Mine equipment	26,566,000	35,380,000	45,807,000
Draglines and bucket wheel excavators	37,389,000	37,916,000	131,763,000
Working capital[2]	4,617,000	5,724,000	10,152,000
Total	168,575,000	179,023,000	287,725,000

[1]Cost of property required for 20-yr operation.
[2]Working capital equals 90 days' operating cost.

TABLE C-2. - Estimated annual operating costs, conventional mining system, at 1.6 million short tons of product per year[1]

Overburden, ft	50	100	150
DRAGLINE SYSTEM			
Direct:			
Power	$901,938	$1,005,908	$1,005,908
Fuel	58,771	82,280	82,280
Supplies	328,213	382,532	382,532
Mobile mine support equipment	333,037	466,252	466,252
Outside services	359,293	359,293	359,293
Direct operating labor	892,079	1,227,241	1,227,241
Direct production supervision	380,605	520,784	520,784
Maintenance labor	270,091	397,526	397,526
Maintenance supervision	159,648	234,339	234,339
Maintenance parts and supplies	1,172,478	1,873,659	1,873,659
Replacement mine pipe	120,972	241,944	241,944
Payroll overhead	411,283	575,907	575,907
Indirect:			
Administrative, technical, and clerical labor	397,526	514,341	514,341
Administrative payroll overhead	95,435	123,470	123,470
Facilities maintenance and supplies	24,638	31,859	31,859
General overhead	31,694	42,835	46,755
Fixed:			
Local taxes	2,511,152	2,558,546	2,558,546
Insurance	33,332	33,332	33,332
BUCKET WHEEL EXCAVATOR SYSTEM			
Direct:			
Power	NAp	NAp	1,418,549
Maintenance supplies	NAp	NAp	4,038,390
Operating and maintenance labor	NAp	NAp	3,003,741
Indirect: Administrative, technical, and clerical labor, facilities maintenance and supplies	NAp	NAp	1,547,685
Fixed: Local taxes and insurance	NAp	NAp	309,537
Total	8,482,185	10,672,048	20,993,870

NAp Not applicable.

[1]Precise production value, 1,666,590 short tons.

TABLE C-3. - Estimated annual operating costs, conventional mining system, at 3.3 million short tons of product per year[1]

Overburden, ft	50	100	150
DRAGLINE SYSTEM			
Direct:			
Power	$1,925,765	$2,106,357	$2,106,357
Fuel	82,280	105,788	105,788
Supplies	490,972	544,627	544,627
Mobile mine support equipment	466,252	599,467	599,467
Outside services	718,586	718,586	718,586
Direct operating labor	1,227,241	1,562,404	1,562,404
Direct production supervision	520,784	659,263	659,263
Maintenance labor	397,526	524,961	524,961
Maintenance supervision	234,339	300,534	300,534
Maintenance parts and supplies	1,873,659	2,488,121	2,488,121
Replacement mine pipe	349,476	524,213	524,213
Payroll overhead	575,907	737,883	737,883
Indirect:			
Administrative, technical, and clerical labor	514,341	631,864	631,864
Administrative payroll overhead	123,470	151,648	151,648
Facilities maintenance and supplies	31,859	39,151	39,151
General overhead	45,971	61,103	68,943
Fixed:			
Local taxes	4,985,850	5,027,432	5,027,432
Insurance	66,664	66,664	66,664
BUCKET WHEEL EXCAVATOR SYSTEM			
Direct:			
Power	NAp	NAp	2,306,316
Maintenance supplies	NAp	NAp	6,565,727
Operating and maintenance labor	NAp	NAp	3,003,741
Indirect: Administrative, technical, and clerical labor, facilities maintenance and supplies	NAp	NAp	2,172,399
Fixed: Local taxes and insurance	NAp	NAp	434,480
Total	14,630,942	16,850,066	31,340,569

NAp Not applicable.

[1]Precise production value, 3,333,180 short tons.

TABLE C-4. - Estimated annual operating costs, conventional mining system, at 5.0 million short tons of product per year[1]

Overburden, ft	50	100	150
DRAGLINE SYSTEM			
Direct:			
Power	$2,994,996	$3,265,884	$3,265,884
Fuel	82,280	129,297	129,297
Supplies	635,591	742,901	742,901
Mobile mine support equipment	466,252	732,681	732,681
Outside services	1,077,878	1,077,878	1,077,878
Direct operating labor	1,227,241	1,897,566	1,897,566
Direct production supervision	520,784	797,734	797,734
Maintenance labor	397,526	652,396	652,396
Maintenance supervision	234,339	369,072	369,072
Maintenance parts and supplies	1,873,659	3,101,507	3,101,507
Replacement mine pipe	430,124	860,247	860,247
Payroll overhead	575,907	898,472	898,472
Indirect:			
Administrative, technical, and clerical labor	514,341	749,382	749,382
Administrative payroll overhead	123,470	179,852	179,852
Facilities maintenance and supplies	31,859	46,433	46,433
General overhead	52,977	79,361	91,121
Fixed:			
Local taxes	7,415,325	7,498,490	7,498,490
Insurance	100,003	100,003	100,003
BUCKET WHEEL EXCAVATOR SYSTEM			
Direct:			
Power	NAp	NAp	3,057,864
Maintenance supplies	NAp	NAp	8,705,272
Operating and maintenance labor	NAp	NAp	3,003,741
Indirect: Administrative, technical, and clerical labor, facilities maintenance and supplies	NAp	NAp	2,701,258
Fixed: Local taxes and insurance	NAp	NAp	540,252
Total	18,754,552	23,179,156	41,199,303

NAp Not applicable.

[1]Precise production value, 5,000,135 short tons.

APPENDIX D.--BENEFICIATION SYSTEM CAPITAL AND OPERATING COSTS

TABLE D-1. - Estimated capital requirements, beneficiation system

Annual mining rate, short tons of product	Mill plant	Working capital[1]	Total
1,666,590	$35,500,000	$702,000	$36,202,000
3,333,180	53,808,000	1,314,000	55,122,000
5,000,135	68,628,000	1,890,000	70,518,000

[1]Working capital equals 90 days' operating cost.

TABLE D-2. - Estimated annual operating costs, beneficiation system

Short tons of product	1,666,590	3,333,180	5,000,135
ANNUAL COST			
Power and labor	$949,956	$1,533,263	$2,050,055
Reagents	1,433,268	2,866,535	4,300,116
Fixed costs	447,479	894,959	1,342,536
Total	2,830,703	5,294,757	7,692,707
COST PER SHORT TON OF PRODUCT[1]			
Power and labor	$0.57	$0.46	$0.41
Reagents	.86	.86	.86
Fixed costs	.27	.27	.27
Total	1.70	1.59	1.54

[1]Rounded to the nearest cent.

APPENDIX E.--CASH FLOW ANALYSIS

TABLE E-1. - Cash flow analysis at 50-ft overburden and 1.6 million short tons of product per year

(Based on annual revenue of $49,995,506)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	$56,998,666	-$56,998,666	0	$56,998,666	-$56,998,666	0
1.....	24,801,333	-4,621,091	0	38,364,333	-10,131,711	0
2.....	0	18,593,989	0	0	25,020,969	0
3.....	0	18,939,770	0	0	25,366,750	0
4.....	0	18,939,770	0	0	25,366,750	3.43
5.....	0	18,939,770	4.88	0	25,366,750	10.27
6.....	0	18,939,770	9.28	0	25,366,750	14.32
7.....	0	18,939,770	12.15	0	25,366,750	16.91
8.....	0	18,939,770	14.11	0	25,366,750	18.63
9.....	0	18,915,664	15.49	0	24,585,359	19.79
10.....	0	18,915,664	16.49	0	24,585,359	20.62
11.....	440,000	17,326,678	17.17	14,262,000	11,875,593	20.92
12.....	0	17,722,678	17.70	0	24,711,393	21.39
13.....	0	17,722,678	18.11	0	24,711,393	21.74
14.....	0	17,722,678	18.42	0	24,711,393	22.00
15.....	0	17,722,678	18.67	0	24,711,639	22.20
16.....	0	17,170,993	18.86	0	24,088,639	22.36
17.....	0	16,825,212	19.00	0	23,742,858	22.47
18.....	0	16,479,432	19.12	0	23,397,077	22.56
19.....	0	16,455,325	19.21	0	22,615,686	22.62
20[3]....	-9,823,000	26,278,325	19.32	-10,139,000	32,754,686	22.70

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-2. - Cash flow analysis at 100-ft overburden and 1.6 million short tons of product per year

(Based on annual revenue of $49,995,506)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	$56,998,666	-$56,998,666	0	$56,998,666	-$56,998,666	0
1.....	25,297,333	-5,749,057	0	54,381,333	-25,071,775	0
2.....	0	17,943,924	0	0	24,550,205	0
3.....	0	18,289,705	0	0	24,895,986	0
4.....	0	18,289,705	0	0	24,895,986	0
5.....	0	18,289,705	3.61	0	24,895,986	5.08
6.....	0	18,289,705	8.16	0	24,895,986	9.87
7.....	0	18,289,705	11.12	0	24,895,986	12.93
8.....	0	18,289,705	13.15	0	24,895,986	14.98
9.....	0	18,265,598	14.56	0	23,685,000	16.35
10.....	0	18,265,598	15.63	0	23,685,000	17.34
11.....	440,000	16,601,714	16.34	22,103,000	4,235,581	17.48
12.....	0	16,997,714	16.89	0	24,128,281	18.09
13.....	0	16,997,714	17.32	0	24,128,281	18.55
14.....	0	16,997,714	17.65	0	24,128,281	18.90
15.....	0	16,997,714	17.91	0	24,128,281	19.17
16.....	0	16,440,738	18.11	0	23,282,417	19.38
17.....	0	16,094,957	18.26	0	22,936,636	19.54
18.....	0	15,749,176	18.38	0	22,590,855	19.66
19.....	0	15,725,070	18.48	0	21,379,869	19.75
20[3]....	-10,156,000	25,881,070	18.61	-13,011,000	34,390,869	19.87

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-3. - Cash flow analysis at 150-ft overburden and 1.6 million short tons of product per year

(Based on annual revenue of $49,995,506)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	$56,998,666	-$56,998,666	0	$56,998,666	-$56,998,666	0
1.....	25,794,333	-6,877,890	0	105,256,333	-80,195,134	0
2.....	0	17,293,891	0	0	25,127,728	0
3.....	0	17,639,672	0	0	22,109,579	0
4.....	0	17,639,672	0	0	21,132,638	0
5.....	0	17,639,672	2.31	0	21,132,638	0
6.....	0	17,639,672	7.00	0	21,132,638	0
7.....	0	17,639,672	10.07	0	21,132,638	0
8.....	0	17,639,672	12.17	0	21,132,638	2.35
9.....	0	17,615,565	13.66	0	19,656,906	4.57
10.....	0	17,615,565	14.75	0	19,656,906	6.23
11.....	440,000	15,895,508	15.49	26,936,000	-4,420,477	5.91
12.....	0	16,291,508	16.06	0	19,821,923	7.16
13.....	0	16,291,508	16.51	0	19,821,923	8.12
14.....	0	16,291,508	16.86	0	19,821,923	8.88
15.....	0	16,291,508	17.13	0	19,821,923	9.48
16.....	0	15,729,207	17.35	0	17,705,118	9.91
17.....	0	15,383,426	17.51	0	17,359,337	10.26
18.....	0	15,037,645	17.64	0	17,013,556	10.55
19.....	0	15,013,539	17.75	0	15,537,825	10.77
20[3]....	-10,489,000	25,502,539	17.89	-20,875,000	36,412,825	11.19

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-4. - Cash flow analysis at 50-ft overburden and 3.3 million short tons of product per year

(Based on annual revenue of $99,991,012)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	$102,536,000	-$102,536,000	0	$102,536,000	-$102,536,000	0
1.....	43,943,000	-4,492,214	0	66,319,000	-9,849,125	0
2.....	0	36,683,963	0	0	50,853,452	0
3.....	0	37,208,040	0	0	51,377,529	0
4.....	0	37,208,040	1.00	0	51,377,529	8.55
5.....	0	37,208,040	7.74	0	51,377,529	14.64
6.....	0	37,208,040	11.82	0	51,377,529	18.24
7.....	0	37,208,040	14.47	0	51,377,529	20.51
8.....	0	37,208,040	16.27	0	51,377,529	22.01
9.....	0	37,159,827	17.53	0	50,034,626	23.01
10.....	0	37,159,827	18.43	0	50,034,626	23.71
11.....	880,000	33,981,855	19.05	24,511,000	28,156,710	24.00
12.....	0	34,773,855	19.52	0	50,216,610	24.38
13.....	0	34,773,855	19.87	0	50,216,610	24.66
14.....	0	34,773,855	20.15	0	50,216,610	24.87
15.....	0	34,773,855	20.36	0	50,216,610	25.02
16.....	0	33,837,971	20.52	0	49,138,586	25.14
17.....	0	33,313,894	20.65	0	48,614,510	25.22
18.....	0	32,789,817	20.74	0	48,090,433	25.29
19.....	0	32,741,604	20.82	0	46,747,530	25.33
20[3]....	-18,001,000	50,742,604	20.91	-17,094,000	63,841,530	25.38

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-5. - Cash flow analysis at 100-ft overburden and 3.3 million short tons of product per year

(Based on annual revenue of $99,991,012)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	$102,536,000	-$102,536,000	0	$102,536,000	-$102,536,000	0
1.....	44,936,000	-6,749,045	0	80,643,000	-23,445,615	0
2.....	0	35,383,832	0	0	50,204,362	0
3.....	0	35,907,909	0	0	50,728,439	0
4.....	0	35,907,909	0	0	50,728,439	5.32
5.....	0	35,907,909	6.44	0	50,728,439	12.00
6.....	0	35,907,909	10.66	0	50,728,439	15.94
7.....	0	35,907,909	13.40	0	50,728,439	18.42
8.....	0	35,907,909	15.27	0	50,728,439	20.08
9.....	0	35,859,696	16.58	0	49,150,680	21.18
10.....	0	35,859,696	17.53	0	49,150,680	21.96
11.....	880,000	32,531,928	18.17	28,798,000	23,536,973	22.24
12.....	0	33,323,928	18.66	0	49,455,173	22.67
13.....	0	33,323,928	19.04	0	49,455,173	22.99
14.....	0	33,323,928	19.33	0	49,455,173	23.24
15.....	0	33,323,928	19.56	0	49,455,173	23.42
16.....	0	32,377,460	19.73	0	48,100,176	23.55
17.....	0	31,853,383	19.86	0	47,576,099	23.66
18.....	0	31,329,306	19.97	0	47,052,022	23.73
19.....	0	31,281,093	20.05	0	45,474,264	23.79
20[3]....	-18,668,000	49,949,093	20.15	-19,458,000	64,932,264	23.86

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-6. - Cash flow analysis at 150-ft overburden and 3.3 million short tons of product per year

(Based on annual revenue of $99,991,012)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	$102,536,000	-$102,536,000	0	$102,536,000	-$102,536,000	0
1.....	45,929,000	-9,005,843	0	162,715,000	-102,945,041	0
2.....	0	34,083,734	0	0	45,642,310	0
3.....	0	34,607,811	0	0	45,808,300	0
4.....	0	34,607,811	0	0	45,808,300	0
5.....	0	34,607,811	5.10	0	45,808,300	0
6.....	0	34,607,811	9.47	0	45,808,300	2.77
7.....	0	34,607,811	12.31	0	45,808,300	6.68
8.....	0	34,607,811	14.25	0	45,808,300	9.32
9.....	0	34,559,598	15.62	0	43,800,399	11.11
10.....	0	34,559,598	16.61	0	43,800,399	12.41
11.....	880,000	31,119,483	17.27	36,649,000	10,801,954	12.66
12.....	0	31,911,483	17.79	0	43,786,054	13.49
13.....	0	31,911,483	18.19	0	43,786,054	14.13
14.....	0	31,911,483	18.50	0	43,786,054	14.62
15.....	0	31,911,483	18.74	0	43,786,054	15.01
16.....	0	30,954,398	18.92	0	40,366,437	15.29
17.....	0	30,430,321	19.07	0	39,842,360	15.52
18.....	0	29,906,244	19.18	0	39,318,283	15.70
19.....	0	29,858,031	19.27	0	37,310,382	15.84
20[3]....	-19,334,000	49,192,031	19.39	-31,657,000	68,967,382	16.05

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-7. - Cash flow analysis at 50-ft overburden and 5.0 million short tons of product per year

(Based on annual revenue of $149,986,517)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	$145,755,000	-$145,755,000	0	$145,755,000	-$145,755,000	0
1.....	61,914,000	-3,324,061	0	93,338,000	-7,787,912	0
2.....	0	54,724,763	0	0	77,535,412	0
3.....	0	55,393,187	0	0	78,203,836	0.44
4.....	0	55,393,187	2.75	0	78,203,836	11.29
5.....	0	55,393,187	9.24	0	78,203,836	17.01
6.....	0	55,393,187	13.16	0	78,203,836	20.38
7.....	0	55,393,187	15.70	0	78,203,836	22.49
8.....	0	55,393,187	17.41	0	78,203,836	23.88
9.....	0	55,320,867	18.61	0	76,748,375	24.80
10.....	0	55,320,867	19.47	0	76,748,375	25.45
11.....	1,320,000	50,553,909	20.04	26,566,000	52,721,578	25.76
12.....	0	51,741,909	20.48	0	76,630,978	26.10
13.....	0	51,741,909	20.82	0	76,630,978	26.34
14.....	0	51,741,909	21.07	0	76,630,978	26.52
15.....	0	51,741,909	21.27	0	76,630,978	26.66
16.....	0	50,455,775	21.42	0	74,870,050	26.75
17.....	0	49,787,351	21.53	0	74,201,627	26.82
18.....	0	49,118,927	21.62	0	73,533,203	26.88
19.....	0	49,046,608	21.69	0	72,077,743	26.92
20[3]....	-25,820,000	74,866,608	21.77	-22,424,000	94,510,743	26.96

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-8. - Cash flow analysis at 100-ft overburden and 5.0 million short tons of product per year

(Based on annual revenue of $149,986,517)

Year	Borehole mining: Capital expenditure	Borehole mining: Cash flow	Borehole mining: Continuous rate of return,[1] pct	Conventional mining: Capital expenditure	Conventional mining: Cash flow	Conventional mining: Continuous rate of return,[1] pct
0[2]....	$145,755,000	-$145,755,000	0	$145,755,000	-$145,755,000	0
1.....	63,376,000	-6,625,651	0	103,786,000	-19,106,615	0
2.....	0	52,830,773	0	0	75,730,609	0
3.....	0	53,499,196	0	0	76,399,033	0
4.....	0	53,499,196	1.27	0	76,399,033	9.01
5.....	0	53,499,196	7.96	0	76,399,033	15.10
6.....	0	53,499,196	12.01	0	76,399,033	18.68
7.....	0	53,499,196	14.64	0	76,399,033	20.94
8.....	0	53,499,196	16.42	0	76,399,033	22.42
9.....	0	53,426,877	17.67	0	74,460,651	23.41
10.....	0	53,426,877	18.57	0	74,460,651	24.11
11.....	1,320,000	48,435,225	19.17	35,380,000	42,759,481	24.40
12.....	0	49,623,225	19.63	0	74,601,481	24.77
13.....	0	49,623,225	19.99	0	74,601,481	25.04
14.....	0	49,623,225	20.26	0	74,601,481	25.24
15.....	0	49,623,225	20.46	0	74,601,481	25.39
16.....	0	48,321,182	20.62	0	72,825,164	25.50
17.....	0	47,652,758	20.74	0	72,156,741	25.59
18.....	0	46,984,334	20.84	0	71,488,317	25.65
19.....	0	46,912,015	20.92	0	69,549,935	25.69
20[3]....	-26,792,000	73,704,015	21.01	-25,346,000	94,895,935	25.74

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-9. - Cash flow analysis at 150-ft overburden and 5.0 million short tons of product per year

(Based on annual revenue of $149,986,517)

Year	Borehole mining			Conventional mining		
	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]....	145,755,000	-$145,755,000	0	$145,755,000	-$145,755,000	0
1.....	64,866,000	-10,011,315	0	212,488,000	-123,280,186	0
2.....	0	50,880,609	0	0	69,831,638	0
3.....	0	51,549,032	0	0	70,500,062	0
4.....	0	51,549,032	0	0	70,500,062	0
5.....	0	51,549,032	6.60	0	70,500,062	1.28
6.....	0	51,549,032	10.80	0	70,500,062	6.77
7.....	0	51,549,032	13.53	0	70,500,062	10.25
8.....	0	51,549,032	15.38	0	70,500,062	12.58
9.....	0	51,476,713	16.68	0	67,990,429	14.16
10.....	0	51,476,713	17.63	0	67,990,429	15.31
11.....	1,320,000	46,316,540	18.25	45,807,000	26,521,260	15.65
12.....	0	47,504,540	18.74	0	67,747,560	16.33
13.....	0	47,504,540	19.11	0	67,747,560	16.86
14.....	0	47,504,540	19.40	0	67,747,560	17.26
15.....	0	47,504,540	19.62	0	67,747,560	17.57
16.....	0	46,186,589	19.79	0	63,229,012	17.80
17.....	0	45,518,165	19.93	0	62,560,588	17.98
18.....	0	44,849,741	20.03	0	61,892,164	18.12
19.....	0	44,777,422	20.11	0	59,382,532	18.23
20[3]....	-27,792,000	72,569,422	20.22	-41,244,000	100,626,532	18.38

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-10. - Cash flow analysis, borehole mining, at 230-ft overburden and 1.6 million short tons of product per year

(Based on annual revenue of $49,995,506)

Year	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Year	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]...	$56,998,666	-$56,998,666	0	11....	440,000	14,743,062	14.08
1....	26,588,333	-8,682,988	0	12....	0	15,139,062	14.70
2....	0	16,253,793	0	13....	0	15,139,062	15.18
3....	0	16,599,573	0	14....	0	15,139,062	15.56
4....	0	16,599,573	0	15....	0	15,139,062	15.86
5....	0	16,599,573	0.14	16....	0	14,568,288	16.10
6....	0	16,599,573	5.08	17....	0	14,222,507	16.28
7....	0	16,599,573	8.32	18....	0	13,876,726	16.42
8....	0	16,599,573	10.55	19....	0	13,852,620	16.54
9....	0	16,575,467	12.13	20[3]...	-11,022,000	24,874,620	16.72
10....	0	16,575,467	13.30				

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-11. - Cash flow analysis, borehole mining, at 230-ft overburden and 3.3 million short tons of product per year

(Based on annual revenue of $99,991,012)

Year	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Year	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]...	$102,536,000	-$102,536,000	0	11....	880,000	28,814,625	15.80
1....	47,518,000	-12,616,907	0	12....	0	29,606,625	16.36
2....	0	32,003,570	0	13....	0	29,606,625	16.79
3....	0	32,527,647	0	14....	0	29,606,625	17.13
4....	0	32,527,647	0	15....	0	29,606,625	17.39
5....	0	32,527,647	2.87	16....	0	28,632,560	17.60
6....	0	32,527,647	7.48	17....	0	28,108,483	17.76
7....	0	32,527,647	10.49	18....	0	27,584,406	17.88
8....	0	32,527,647	12.56	19....	0	27,536,193	17.99
9....	0	32,479,434	14.20	20[3]...	-20,400,000	47,936,193	18.13
10....	0	32,479,434	15.09				

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

TABLE E-12. - Cash flow analysis, borehole mining, at 230-ft overburden and 5.0 million short tons of product per year

(Based on annual revenue of $149,986,517)

Year	Capital expenditure	Cash flow	Continuous rate of return,[1] pct	Year	Capital expenditure	Cash flow	Continuous rate of return,[1] pct
0[2]...	$145,755,000	-$145,755,000	0	11....	1,320,000	42,859,237	16.75
1....	67,249,000	-15,427,477	0	12....	0	44,047,237	17.27
2....	0	47,760,347	0	13....	0	44,047,237	17.68
3....	0	48,428,770	0	14....	0	44,047,237	17.99
4....	0	48,428,770	0	15....	0	44,047,237	18.24
5....	0	48,428,770	4.34	16....	0	42,703,832	18.43
6....	0	48,428,770	8.78	17....	0	42,035,408	18.58
7....	0	48,428,770	11.68	18....	0	41,366,984	18.70
8....	0	48,428,770	13.66	19....	0	41,294,665	18.79
9....	0	48,356,451	15.06	20[3]...	-29,391,000	70,685,665	18.92
10....	0	48,356,451	16.07				

[1]Discounted cash flow rate of return at $30 per short ton of phosphate rock product.
[2]Year 0 equals total preproduction years.
[3]Equipment value and working capital salvaged in year 20.

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