EVALUATION OF THE PHOSPHATE DEPOSITS OF FLORIDA USING THE MINERALS AVAILABILITY SYSTEM

FINAL REPORT

Prepared for

**UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES**

CONTRACT NO. J0377000

by

**ZELLARS - WILLIAMS, INC.
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JUNE 1978

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Final	2.	3. Recipient's Accession No.

4. Title and Subtitle

Evaluation of the Phosphate Deposits of Florida
Using the Minerals Availability System

5. Report Date

June 1978

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

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10. Project/Task/Work Unit No.

Phase IV

11. Contract(C) or Grant(G) No.

(C) J0377000

(G)

12. Sponsoring Organization Name and Address

U. S. Department of the Interior
Bureau of Mines
4800 Forbes Avenue, Pittsburgh, Pennsylvania 15213

13. Type of Report & Period Covered

Final
June 1977–June 1978

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

        The Bureau of Mines through their contractor, Zellars-Williams, Inc.
(ZWI), conducted a twelve month investigation of Florida phosphate re-
sources for entry into the Minerals Availability System (MAS). Data was
collected from known literature, mineral interests now developing or pro-
ducing phosphate rock, large landholders, and governmental agencies on a
regional, deposit summary, or individual prospect hole data base. Operat-
ing and capital cost estimates assignable in the MAS to operating or
projected ("C") deposits were prepared by modeling six case mines, based
on nominal ranges of size, age, and quality of ore. These cases provided
the basis for development of a computer program by ZWI to also project
costs for "R" deposits (other identified deposits). These cost, environ-
mental, geographic and other relevant data were encoded into the MAS
format, as well as probabilistic grade-resource quantification. In
addition, a Summary Deposit File report was written for each of the 103
("C" and "R") deposits identified in the study. This report represents
a compilation of the deposit information gathered, presented with
descriptive historic or technical background data.

17. Document Analysis   a. Descriptors

Phosphate   Recovery
Availability   Cost Estimates
Deposits
Resources

b. Identifiers/Open-Ended Terms

Phosphate – Availability of Florida Deposits

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) Unclassified	21. No. of Pages
Release Unlimited	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18)   See Instructions on Reverse

OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

FOREWORD

This report was prepared by Zellars-Williams, Inc.,
Lakeland, Florida under USBM Contract number J0377000.
The contract was initiated under the Minerals
Availability System Program. It was administered
under the technical direction of Eastern Field
Operations Center, Pittsburgh, Pennsylvania with
Eugene C. Baker acting as Technical Project Officer
and C. P. Mishra as Project Monitor. Patrick J.
Neary was the contract administrator for the Bureau
of Mines. This report is a summary of the work
recently completed as a part of this contract during
the period June 1977 to June 1978. This report was
submitted by the authors on June 5, 1978.

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INTRODUCTION

Phosphate rock has been mined in Florida since late in the nine-
teenth century. By early in the twentieth century, the industry had
taken a position of world leadership in rock production. It has been
able to maintain this position by: (1) the high quality of both ore
processed and the resulting product, (2) the ore's amenability to
extraction by relatively inexpensive methods, (3) the availability of
water resources necessary to maximize recovery and provide effective
hydraulic transportation, (4) its geographic position relative to port
areas, climate, and topography, (5) competitive energy costs, and (6)
the ability of the industry to provide continuing technological
leadership in providing more efficient methods and equipment for
mining and concentrating the ore. These factors have allowed phosphate
rock in Florida to be produced at a very low cost - a cost that until
recently controlled both domestic and world prices for phosphate rock
and fertilizer products.

In recent years, considerable attention has been focused on the
Florida phosphate industry and its ability and potential to continue
to maintain an adequate supply for domestic and world demand. The
question of its ability has been posed primarily by the following
developments: (1) the high quality reserves of Polk and Hillsborough
Counties have been depleted to a point where mine terminations and
exhaustion of these resources is projected within this century, (2)
foreign producers, particularly Morocco, have developed aggressive
marketing of high grade resources and influenced market value, (3) cost
of producing lower grade resources in the state against competitive
price ceilings raises the question of competitive and viable economics
for new development, (4) some constraints in physical extraction, such
as concentrating poorer quality ore and deeper mining, are identifi-
able, (5) environmental regulations have proliferated in recent years,
and (6) competition for water and energy resources as a result of
rapid population growth has the potential of restricting recovery of
some portion of the resources and discouraging new development. On
the other hand, there has been in the past five years considerable
interest by private companies in acquiring and proceeding to develop
future resources, with incentive provided by possible future shortage
in resources or production capacity and a limit on the remaining
deposits; price decreases in the past two years have dampened this to
some extent.

The above economic, technological, or environmental constraints
could serve to limit Florida's ability to sustain or develop future
reserves sufficient to maintain world position, or more crucially,
domestic requirements necessary for food production. If such becomes

the case, the United States would be required to rely on other domestic resources which would have a similar set of contraints, or depend on foreign sources. Thus there is an acute interest in the state's capability for future phosphate rock production. A supplemental interest has also developed for recent uranium price increases and advances in the technology of uranium extraction from phosphoric acid (an intermediate stage in fertilizer production), and the phosphate industry's potential contribution to uranium resources.

In response to these interests and concerns the U. S. Bureau of Mines in June 1977 through its contractor, Zellars-Williams, Inc., initiated an evaluation of the phosphate deposits of Florida using the Minerals Availability System (MAS). The prime function of MAS is to classify reserves through geologic, engineering and economic evaluation of identified resources. The objective was "to accumulate available information on the occurrence of phosphate in land pebble areas of Northern and Central Florida and make this information available to the MAS"[1]. The study area, as shown in figures 1 and 8, actually included all

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[1] U. S. Bureau of Mines Contract J0377000, June 1977.

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identified resources within the boundaries of the state. The Minerals Availability System is a

> component of the Bureau of Mines minerals intelligence
> function designed to conduct and maintain an inventory
> of minerals important to the Nation. The system involves
> the evaluation and classification of mineral resource
> information for automated storage and retrieval. The MAS
> file serves as an information base for minerals and avail-
> ability studies to determine the Nation's minerals supply
> position[2].

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[2] U. S. Bureau of Mines and U. S. Geological Survey. The Bureau of Mines Minerals Availability System and Resource Classification. BuMines IC 8654, 1976, 5 pp.

A summary description of the system from the referenced manual is in appendix A. Maintenance and periodic update is the responsibility of the Bureau of Mines.

The system allows several categorizations of deposits for MAS entry based on development timing and levels of data available. For the Florida study, "C" deposits were those identified as "active or projected", "R" for other identified quantifiable deposits, and "L" for identified unquantified deposits. "C" entries require the greatest level of informational input, including at least thirteen encodement records regarding deposit identification, characteristics, costs, and resource grade-quantity matrices. "R" reduces the number of entries, mostly in the area of mining-beneficiation system description and cost
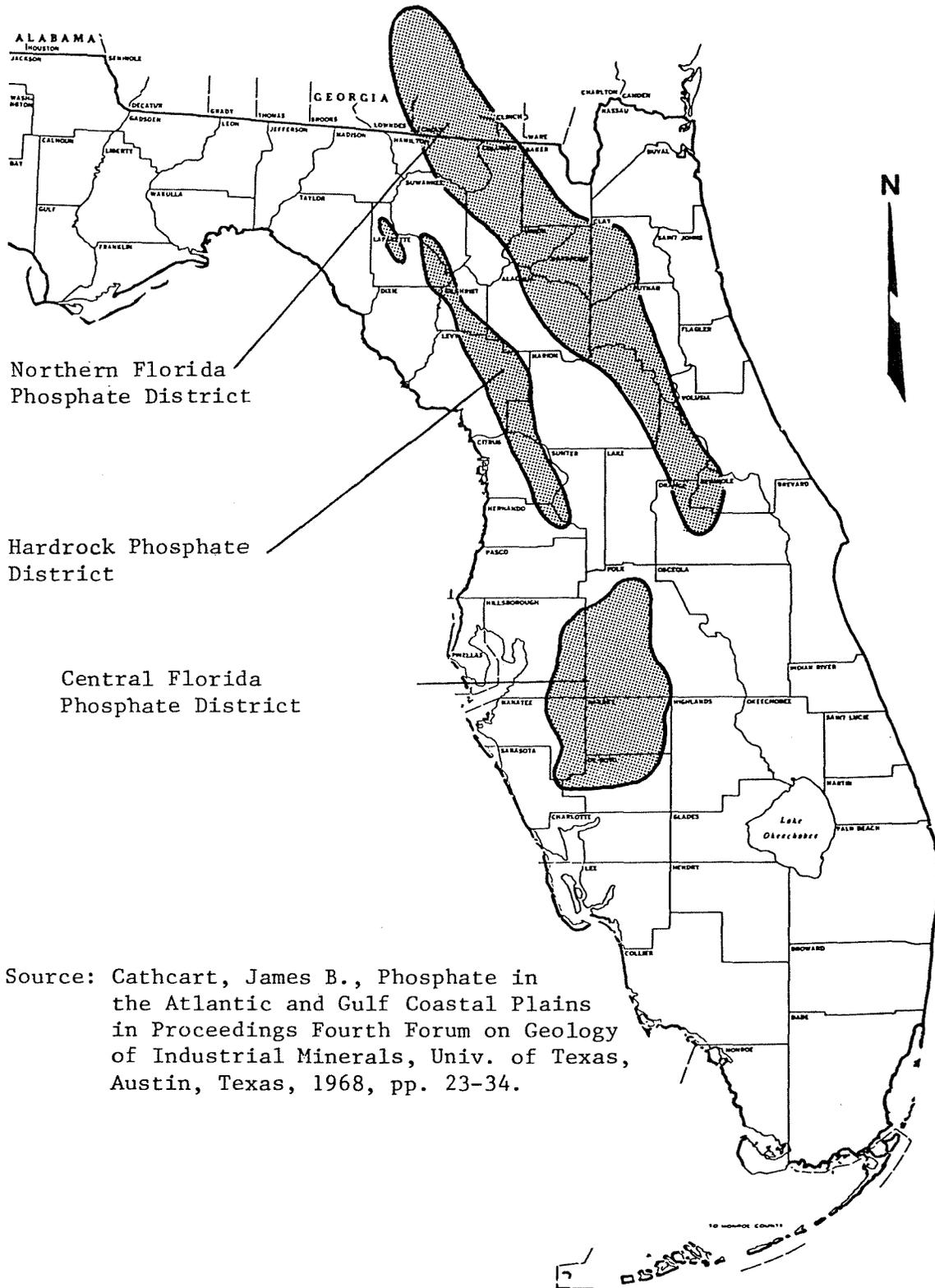
Northern Florida
Phosphate District

Hardrock Phosphate
District

Central Florida
Phosphate District

Source: Cathcart, James B., Phosphate in
the Atlantic and Gulf Coastal Plains
in Proceedings Fourth Forum on Geology
of Industrial Minerals, Univ. of Texas,
Austin, Texas, 1968, pp. 23-34.

FIGURE 1. - Previously recognized phosphate districts.

data. "L" requires only naming and location of deposit. The Minerals Availability System is designed to handle various levels of confidence or "probability" based on data, source, and reliability; it considers, however, only <u>identified</u> deposits. Figure 2 is a diagrammatic classi- fication of mineral resources[3]. This study is concerned only with the

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[3] U. S. Geological Survey. Principles of the Mineral Resource Classi- fication System of the U. S. Bureau of Mines and the U. S. Geol. Survey. Bull. 1450-A, 1976, p. A2.

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left side of the diagram, or "identified" resources and not those "un- discovered" on the right side which includes hypothetical and speculative deposits in known districts. The study corresponds measured resources with confidence levels of >75%, indicated 25-75% and inferred <25%. "Reserves" correspond with ore that can produce rock product below market prices; the remainder is sub-economic resources.

TOTAL RESOURCES

← Increasing Degree of Geologic Assurance
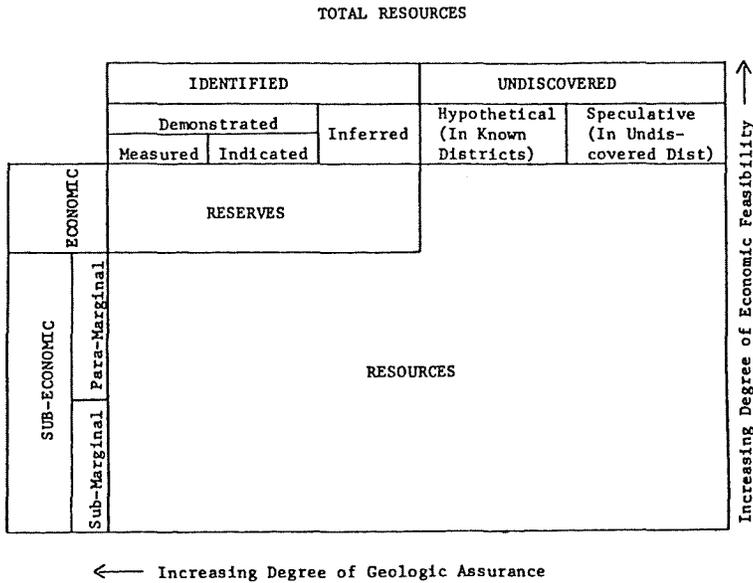
FIGURE 2. - Classification of resources.

Zellars-Williams, Inc.'s approach to the study was to identify all deposits containing a minimum established level of resource concentration, which is described later in the report. The deposits can be owned or controlled by either companies in the phosphate minerals/chemicals industry or by others, and located inside or outside of previous district delineations. For each deposit, the salient information consists of:

- Size and quality of resource and product.
- Technological feasibility of recovery.
- Environmental sensitivity.
- Economics in terms of capital and production costs.

For identification and location of deposits, known sources of information were interviewed, including governmental agencies, area consultants and industry personnel. In the case of industry, a questionnaire was prepared to organize information and indicate to the individual or company the type and depth of information required for MAS entry. It allowed each company's staff to supply information at some convenience, and its management to review the data prior to its release. In addition to interviews, literature on Florida phosphate occurrence was reviewed, and informational sources were cross-checked. All information offered in confidence has been identified in each deposit file. This report is prepared to summarize the individual deposit information in a non-confidential manner. Information collected was often incomplete due to lack of data or reluctance of some parties to divulge proprietary information. Although participation and cooperation of sources was mixed, overall response was excellent and sufficient to give a sound level of confidence to the resource information collected.

Primary recovery difficulties for Florida deposits are practical removal of thick (greater than fifty feet) layers of usually poorly consolidated wet overburden, mine recovery of mineable zones within vertically discontinuous ore, and concentration (beneficiation) of more calcareous ores. As a basis for evaluating technical recovery feasibility, Zellars-Williams, Inc. relied upon in-house knowledge of available earth-moving equipment, knowledge of soil stability characteristics, and our experience with metallurgical response of lower grade ores. One company shared its opinion of the feasibility and economics of dolomite and calcite rejection. Categorized as a separate matrix, where identifiable, are those resources sufficiently high in dolomite (MgO) to be considered presently unmineable in terms of demonstrated technology. Evidence that such technology is or will be available for rejection of free dolomite is convincing. Whether this rejection is sufficient to make an acceptable product in terms of locked MgO, and the economic effect of this process are presently undetermined. When such a process becomes viable, the resource can then be recategorized based on economics as a reserve or resource.

Environmental sensitivity of specific deposits is considered in
the MAS evaluation as input, and is appropriate to Florida deposits.
The system requires a rating for each deposit in terms of land,
vegetation, wildlife, water, air, aesthetics, sound and an overall rating
for both the short (during mining) and long term (after mining). A
numerical rating of 0 (undetermined) to 6 (prohibitive) is provided for
environmental sensitivity. The system's basis is sensitivity - or
"people's reaction" - rather than actual environmental qualification,
if such were possible. Thus, judgement is required to indicate any
significant characteristics of ore areas that might prove restrictive
to mining activity. The approach to this assessment was to review these
areas with several regulatory agencies for their reaction as to sensitivity
of each of the above listed areas, and apply "in-house" judgement to each
case.

Sensitivity varies for deposits based primarily on their location,
both in regard to possible stress on natural systems and past public
reaction by citizens, media, or local government. Those underlying
extremely sensitive areas on the property were removed from total
resources (if not already done by the owner/operator), such as beneath
lakes and major streams. In some cases, a portion of the resources was
placed in a separate matrix (category) based on environmental sensitivity.
Most, however, received an overall rating. Again, any such subjective
designation is not only argumentative, but subject to future change
depending on public attitude or technical problem identification and
solutions.

The past decade has witnessed a multitude of identified environmental
issues associated with mining or processing, a number of which have been
resolved. Thus, the environmental rating applied to each deposit in this
study will need periodic review along with their associated resources.
The ratings, however, reflect our best judgement of public concern.

The most important factor in assessing Florida phosphate resources
remains economics, as defined by the operating and capital costs of
mining and milling (beneficiation). Application of economic criteria
defines or segregates each deposit in terms of reserves and sub-economic
resources under prevailing markets. The evaluation of the potential of
Florida to maintain adequate production supply by private industry must
consider the present and future costs of development and production of
resources to be exploited. Thus, a reasonably accurate cost assignment
is important to each deposit, whether it is designated as a "C" (required
for MAS entry) or "R".

Cost data for existing or developing deposits is generally closely
held information considered proprietary in a competitive industry. Two
or three companies in the field have publicly offered cost data, and a
few others were willing to contribute to the study experienced or projected
cost information. Zellars-Williams, Inc. recognized prior to the study's
initiation that such cost information would not only be difficult to
obtain, but, due to different cost accounting methods, information would

be misleading if not identifiable on a common basis. It was therefore proposed that operating and capital cost models be prepared in the course of the study. These models are sufficiently documented to test their accuracy in representing typical costs based on associated cost related factors (ore richness, plant capacity, age, etc.), and adequately detailed to be broken down into common expense areas (see cost sections). Models were tested against and calibrated by known deposit cost experience. This exercise led to the development of a computer model which uses twenty-one cost sensitive factors to estimate operating costs. The computer model was also tested by known "C" deposits and found to be sufficiently accurate to project typical costs. This work allowed a cost to be assigned to each "C" and "R" deposit in the state, and permitted categorization by projectable economics. This resolution forms the basis for deposit and resource characterization results in the final section of this report.

A final exercise in resource identification and quantification is assignment of probability. Probability is a ranking procedure that allows assignment of more than one resource quantity or grade based on various levels of information; it was used in this study primarily to describe the level of confidence assigned to a resource description. A resource defined by dense drilling control, based on direct information supplied, and supported by experienced production and/or secondary information sources would be assigned a 90% probability level. At the other end of the scale, resources inferred from surrounding data without contribution by the owner/operator or supporting prospecting would be assigned a 10% probability. This assignment uses geological inference as an identification basis and was used sparingly in quantifying deposits.

To summarize, the approach to the identification and study of Florida's identified resources included:

- Investigation and research to identify and characterize deposits.
- Study and assignment of environmental sensitivity and related data.
- Preparation of capital and operating cost models.
- Assignment of data to individual deposits, encoding into MAS entry forms and preparation of individual summary file reports.
- Compilation and evaluation of combined resource data for this report.

Encodement into MAS for Florida phosphate resources is not a straightforward procedure. The system is designed to accept all mineral deposits, most of which have resources quantified by tons of ore, which is not the traditional Florida expression of recoverable product. For system entry (and subsequent accurate retrieval), it was necessary to formulate ore resources (and associated costs) in P_2O_5 units from resources expressed

and offered in product BPL units. Establishment of units, densities, and ratios of concentration (what is variously calculated and expressed by various owner/operators) was necessary for purposes of MAS entry and retrieval, and proved to be an extensive undertaking. The point of the conversion is to present resources in units acceptable to the MAS system that are retrievable and convertible to traditional expressions of resources.

The sections that follow are descriptive of the elements and the results of the year-long study organized into major categories of background (geology and production history), deposit characterization, mining, processing, regulatory and environmental considerations, deposit identification, deposit characterization, and production capacity. A final chapter offers conclusions and observations on the study and the state's phosphate resource potential.

ACKNOWLEDGEMENTS

BACKGROUND

Depositional History and Origin of Phosphorites of Florida

The Tertiary Period of geologic history in the Atlantic Coastal Plain of the eastern United States was quite unusual because of an extraordinary accumulation of phosphate. Although marine sedimentary phosphate is present in most strata of Cretaceous to Holocene time in the region, the commercially economic deposits are contained in sediments of Middle Miocene and Pliocene ages.

It is beyond the scope of this report to attempt to synthesize all of the studies performed and literature as to the origin of phosphorite. There are divergent opinions on phosphorogenesis. No single hypothesis accounts for all of the phosphate deposited; it is reasonable to rely upon different ideas to explain the phosphorogenesis in different locations which were subject to various conditions, through time.

Briefly, four interacting sets of conditions must be considered when discussing the origin and accumulation of phosphorites. These are:

- The regional structural configuration of the basins of deposition; that is, the paleogeography of land and sea.

- The inorganic chemical and biochemical systems functioning at the time of primary deposition.

- The secondary or the nth cycle reworking of previously deposited phosphate, which is compounded by physical, textural modifications, and perhaps the addition of new phosphate in a marine environment.

- In situ leaching or residual enrichment and diagenetic changes following deposition of the first and/or n^{th} cycle material.

Structural Control

Sedimentary phosphorite of economic concentration accumulated in depositional basins which were in proximity to the open, circulating seas. These depocenters could have existed because of the topographic relief created by the elevation of surrounding areas or by subsidence of a portion of a continental shelf, or both. It does not appear to be important whether the basins were fault or flexure caused. It was, however, necessary that basin development be concomitant with abundant phosphorite accumulation for both primary sedimentation and secondary or reworked deposition. These principles of syntectonic deposition were initially espoused by P. D.

Krynine in the 1940's[4], and later refined by W. D. Lowry in the 1950's[5]

[4] Krynine, P. D. Differential Sedimentation and Its Products During One Complete Geosynclinal Cycle. Proc. First Pan American Congress of Mining Engineering and Geology, Chile, 1942, pt.1, pp. 537-560.

[5] Lowry, W. D. Are the Depressions of Major Folds of the Valley and Ridge Province of Virginia of Depositional Origin? Mineral Industries Journal (Virginia Polytechnical Institute), v. 2, No. 2, 1955, p. 58.
_____. Implications of Gentile Ordovicion Folding in Western Virginia. A.A.P.G. Bulletin, v. 41, 1957, pp.643-655.
_____. Relationship Between Tectonism and Sedimentation in Early Silurian time in Virginia. Mining Industry Journal (Virginia Poly-technical Institute), v. 7, No. 3, 1960, pp.1-7.

and B. N. Cooper during the 1960's and early 1970's[6].

[6] Cooper, B. N. Relation of Stratigraphy to Structure in the Southern Appalachians: in Tectonics of the Southern Appalachians, ed. by W. D. Lowry. Virginia Polytechnical Institute, Department of Geological Science, Memo. 1, 1964, pp. 81-114.

The entrapment basins upon the continental margin profoundly affected the nearshore circulatory patterns which, in turn, changed the chemical system to foster phosphate precipitation. In addition, the topographically higher areas bordering the basins later became local or regional source areas of previously deposited phosphate.

Figure 3 is a structural contour map drawn in the base of the "ore zone", or that zone of most concentrated phosphorite in the Hawthorn. Caution must be exercised when interpreting structure contour maps with the intent of locating basins of phosphorite deposition. In most locations, the erosional relief is greater than the structural relief. This is especially true in carbonate terraces which were exposed during the erosional intervals between the Eocene Ocala Group and the Middle Miocene Hawthorn formation, and between the Hawthorn and the Pliocene Bone Valley (or equivalent) formation. The carbonate strata were subjected to solution (karst) erosion as well as the usual fluvial and littoral erosion. Where units were deposited upon an actively rising structure, either stratigraphic off-lap or subsequent erosional off-lap occurred, thus leaving different "surface" rocks at different locations. Therefore, it is difficult to know if a "high" is erosional, non-depositional, or purely structural. For example, the term "top of Eocene rocks" or "top of Hawthorn" may not mean the stratigraphic top, but the
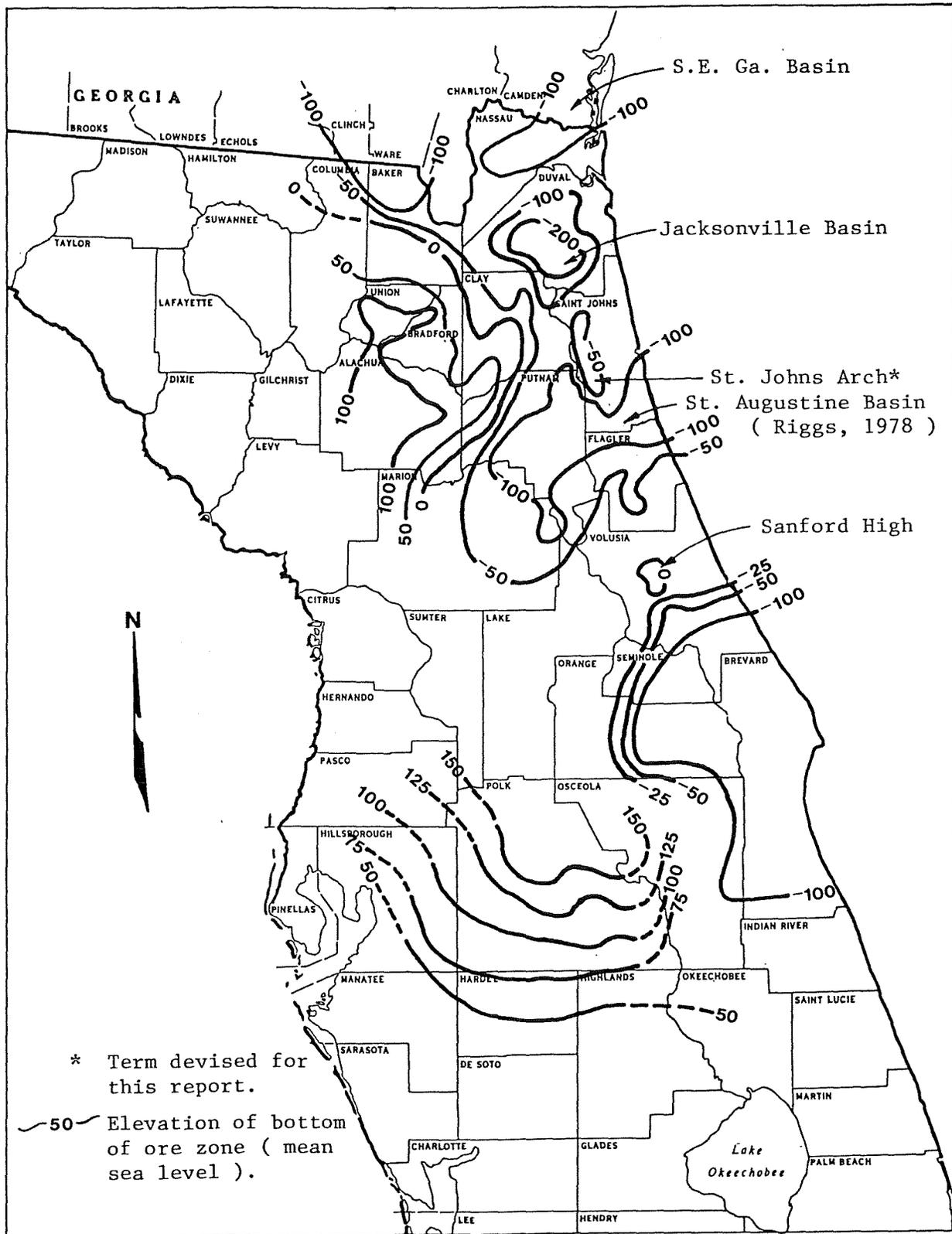
FIGURE 3. – Structure contour map – bottom of ore zone.

erosional (topographic) surface, and may not be representative of struc-
tural activity before, during, or after deposition. What is important
in this discussion is that the buried "highs" and "lows" are relative
topographic and depositional features which can be identified with fair
accuracy, and thus be used to identify loci of deposition, or to predict
trends.

Reference is made to Cathcart's map[7], Vernon's maps[8], Bermes, et al,[9]

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[7] Cathcart, J. B. Phosphate in the Atlantic and Gulf Coastal Plains
in Proceedings Fourth Forum on Geology of Industrial Minerals, ed. L. F.
Brown, Jr. University of Texas, 1968, pp. 23-34.

[8] Vernon, R. O., Geology of Citrus and Levy Counties, Florida. Fla.
Geol. Survey Bull. 33, 1951, p. 256.

[9] Bermes, B. J. et al, Geology and Water Resources of Flagler, Putman
and St. Johns Counties, Florida. Fla. Geol. Survey RI 32, 1963, p. 97.

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and those maps included in this report. Upon examination of the "structure"
maps, many subsurface features become evident. The identified arches,
uplifts, anticlines, domes, or simply "highs" which played an important
role in deposition during the Miocene-Pliocene interval in Florida are:
the Sanford High, Ocala Uplift, Central Florida Platform, a north-south
striking arch in Flagler-St. Johns County and a high in eastern Brevard
County (see figure 3). Synclines, basins, troughs, or "lows" which were
the principal sediment traps are: the Jacksonville Basin, St. Augustine
Basin, S. E. Georgia Basin, and the Polk-Hillsborough Basin. Cathcart
points out that the axes of these "highs" and "lows" are all oriented
in a northeasterly or northwesterly direction.

Inorganic and Biochemical Precipitation

Phosphorus, as all other elements, is derived from igneous source rocks.
The original sources underwent natural weathering and erosion, and
eventually phosphorus was delivered to the seas to play an important role
as a nutrient for animal and plant life. Phosphorus was dissolved in sea
water and much of it taken-up by life forms as new phosphorus was
continually added to the aqueous system.

Sheldon[10] has shown that phosphorites, worldwide and throughout

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[10] Sheldon, R. P. Paleolatitudinal and Paleogeographic Distribution of
Phosphorite. U.S. Geol. Survey Professional Paper 401-C, 1964, pp. 106-113.

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geologic time, have been deposited between the 40th parallels north and
south of the equator. The greatest frequency of occurrence of phosphate
deposition is between 20° and 35°, in two belts north and south. The

reasons for this are warmer sea water temperatures, abundant life forms, and oceanic circulatory patterns created by the trade winds.

Krumbein and Garrels[11] determined the pH and Eh relationships which

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[11] Krumbein, W. C. and R. M. Garrels. Origin and Classification of Chemical Sediments in Terms of pH and Oxidation - Reduction Potentials. J. Geol., v. 60, 1952, pp. 1-33.

---

permit mineral precipitation from sea water. Phosphorite is formed from sea water which is slightly alkaline (pH 7 to 9) and has a range of oxidation from +1 to -3 Eh. That is, it can form under most normal sea water conditions, deep or shallow, with open circulation. Under restricted circulation conditions, phosphorite is precipitated in a humid climatic environment. However, the most favored precipatory conditions are: slightly alkaline (pH 7 to 8) and slightly reducing (Eh 0 to -2), associated with the accumulation of calcite, uranium, and organic material. Further, it has been demonstrated that phosphorite, like calcite, is more soluble in colder water and both would precipitate from warm water.

Therefore, phosphorite was precipitated on the open continental shelf as well as within embayments and estuarine environments. Colder sea water containing more phosphate in solution could have mixed with warmer, low latitude water and warmer, surface waters, thereby initiating pre-cipitation, apparently by at least three mechanisms along the Atlantic Coastal Plains:

- Nearshore, cold water currents from the north followed the coastline southward, entered the basins created by structural activities, and was warmed by shoaling and by mixing with the southern waters.

- The prevailing westerlies transported surface water away from the eastern coast, to be replaced by the "upwelling" deeper water rich in phosphate, thence to be warmed near the surface and by the Gulf Stream.

- Deeper, cool water rose eastward out of the Gulf of Mexico as it passed over the South Florida Shelf. This is probably the case for the South and Central Florida phosphate districts where the Ocala Uplift landmass was flanked by a shallow carbonate shelf during Miocene time.

In addition to the inorganic precipitation of phosphorite, a great deal of phosphatic debris was deposited with dead marine organisms. Plant and animal life in warm, low latitude waters upon the continental shelf is enormously abundant and all of it contains this life-essential element extracted from sea water. Although the larger and more impressive fossils of vertebrates and hard-parts of the invertebrates capture the fascination of collectors, by far the greatest volume of organic debris continuously

"snows" upon the sea floor and accounts for the greatest accumulation from micro-organisms.

It is important to reiterate the significance of the location of the depositional basins with regard to primary phosphorite accumulation by inorganic and biochemical processes. Their position and orientation upon the upper continental shelf in lower latitudes was of vital importance. Reference is made to the following: Kazakov[12], Pevear[13], McConnell[14] and Gulbrandsen[15].

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[12] Kazakov, A. F. The Phosphorite Facils and the Genesis of Phosphorites in Geological Investigation of Agricultural Ores, U.S.S.R. Leningrade Science Institute of Fert. and Insecto-fungicides Trans., 1937, No. 142, pp. 95-113.

[13] Pevear, D. R. The Estuarine Formation of the U. S. Atlantic Coastal Plain Phosphorite. Econ. Geol., v. 61, No. 2, 1966, pp.251-255.

[14] McConnell, C. Precipitation of Phosphates in Sea Water. Econ. Geol., v. 60, No. 5, p. 967.

[15] Gulbrandsen, R. A. Physical and Chemical Factors in the Formation of Marine Apatite. Econ. Geol., v. 64, 1969, No. 4, pp. 365-382.

Reworking of Phosphorite

Once the phosphorite layers had been deposited in basins and upon other portions of the shelf, physical concentration processes began to operate. Penecontemporaneous reworking of newly deposited phosphatic clays by turbulent bottom-currents and storms initiated the "pelletizing" and relocation of clastic phosphate grains (intraclasts) torn loose from the primary beds. Workers who have described these processes are: Altschuler[16], Freas and Riggs[17] (personal communication, 1978).

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[16] Altschuler, Z. S. Precipitation and Recycling of Phosphate in the Florida Land-Pebble Phosphate Deposits. U.S.Geol. Survey Professional Paper 525-B, 1965, pp. 91-95.
_____, J. B. Cathcart, and E. J. Yound. Geology and Geochemistry of the Bone Valley Formation and Its Phosphate Deposits. Geol. Soc. Amer. ann. mtg., Miami Beach 1974 Guidebook, field trip No. 6, 1974, p. 68.

[17] Freas, D. H. and S. R. Riggs. Environments of Phosphorite Deposition in the Central Florida Phosphate District. Proc. Fourth Forum of Geol. of Industrial Minerals, Univ. of Texas, 1968, pp. 117-128.

The phosphorite mud intraclasts were tumbled, rounded and redeposited within the same carbonate formation of primary origin. This unit is now called the Hawthorn formation of middle Miocene age. If facies aspects

of the Hawthorn (and equivalent units) were known, one would probably find that the greatest amount of first-cycle reworked intraclast pellets were formed closer to shore. Farther offshore, where the bottom currents and storms are less turbulent, the undisturbed or less disturbed original phosphatic mud layers remain intact, still interbedded within the Hawthorn carbonates.

Middle Miocene time was one of marine transgression where the sea was farther upon the continent than today. The eastern seaboard probably looked like a vast series of carbonate islands and peninsulas rising from the sea floor. Because of the transgressive position of the sea, little clastic sediment was being carried far from the exposed main portions of the continent, and carbonates were the principal sediment in the Florida region.

It was not until the seas retreated (regressed) from the land during the upper Miocene interval that fluvial systems could become established upon the Hawthorn surface. The new drainage systems, in part assisted by littoral currents, carried clastic - mainly quartzose - sediment from sources in and adjacent to the Appalachian Blue Ridge, the Piedmont, and the older Cretaceous Coastal Plain sediments. More appropriate to this study, as post-Hawthorn erosion cut into the previously deposited carbonate/phosphorite terrain of Florida, the phosphatic pellets were liberated only to be reworked and redistributed into the basins.

Carbonate rock fragments, a new influx of quartz sand detritus, silt, clay, reworked fossil fragments and phosphate grains and pebbles all began to accumulate in the regional lows. The topographically higher terrains shed material off into the nearby depocenters. As Davidson[18]

18/ Davidson, D. F. Relation of the Topography of the Hawthorn Formation to Size of Phosphate Particles in the Deposits, and to Topography, in the Northern Part of the Land-Pebble Phosphate Field, Florida. U.S. Atomic Energy Comm. - U.S.Geol. Survey, TEM-337 (rev.), 1952, 17 pp.

demonstrates, the coarser particles remained closest to the sources, while the finer phosphate grains travelled farther into the basins.

What is now observed in the present phosphate districts is the net result of multi-cycled reworking of phosphate under a variety of environmental conditions. The primary phosphate layers were first disturbed to yield intraclasts within the depositional basin at about the same time as the remainder of the Hawthorn was forming. Later, these pellets were brought back into the erosional-reworking-depositional cycle, perhaps numerous times. The key point is that the cyclic history was concentrating phosphate into economic deposits. Clastic phosphate being reworked in a marine environment would have been combined with newly precipitating phosphate from both inorganic and biological sources.

The "reworked" phosphate deposits occurred during Pliocene time, and are now known as the Bone Valley formation and its equivalents. Because of the diversity of conditions acting upon the Hawthorn surface, there are many diverse and often confusing facies representative of the Bone Valley. Some facies are near shore marine sands and clays, estuarine, fluvial/coastal plain, and even swamp and marsh deposits. Considerable dilution of phosphate occurs far off of structures due to mixing with many other materials in the deeper portions of the continental shelf. The shifting depocenters and multiple reworkings account for the difference between detrital constituents within the ore "matrix". Clay and silt accumulated only in low-energy environments such as lagoons, tidal flats, fluvial back swamps, swamps, and deeper "quiet" waters. Certainly, the Bone Valley deposits were reworked within themsleves before that sequence of deposition came to a close. Some workers (Williams[19] and Clark[20]) have found that

19/ Williams, G. K. Geology and Geochemistry of the Sedimentary Phosphate Deposits of Northen Peninsular Florida. Ph.D. Diss., Florida State University, 1971, 124 pp.

20/ Clark, D. S. Stratigraphy, Genesis and Economic Potential of the Southern Part of the Florida Land-Pebble Phosphate Field, Ph.D. Diss., University of Missouri - Rolla, 1972, 192 pp.

some phosphorite sands are late Pliocene and Pleistocene reworking of Bone Valley deposits.

Two new papers are forthcoming by Riggs which will treat phosphogenesis and present a model based upon studies of Florida's phosphate occurrences: "Petrology of the Tertiary Phosphorite Systems in Florida" and "Phosphorite Sedimentation: Florida, a Model Phosphogenic System" as a part of a symposium volume of Economic Geology. Riggs emphasizes that the greatest concentrations are not the large basins, but the entrapment basins, as previously discussed.

Post-Depositional Changes

Following the deposition of the multi-cycled phosphate materials, additional modifications occurred which either weakened or enriched the concentration of phosphorite. Weathering in the warm, humid, subtropical climate of Florida produced lateritic types of leaching, mobilization and supergene enrichment. Thickness of overlying sediments, (figure 4) depth to water table, permeability, and abundance of vegetation (humic acid) all played a role in the degree of leaching and accumulation of a deposit.

In many locations, an aluminum phosphate zone overlies the calcium phosphate zone within the Bone Valley formation. Apparently, the aluminum phosphates remain during and after leaching of the upper zones, but have showed in many cases as accumulated strata for uranium. The more soluble calcium phosphates percolated downward to enrich the lower zones.
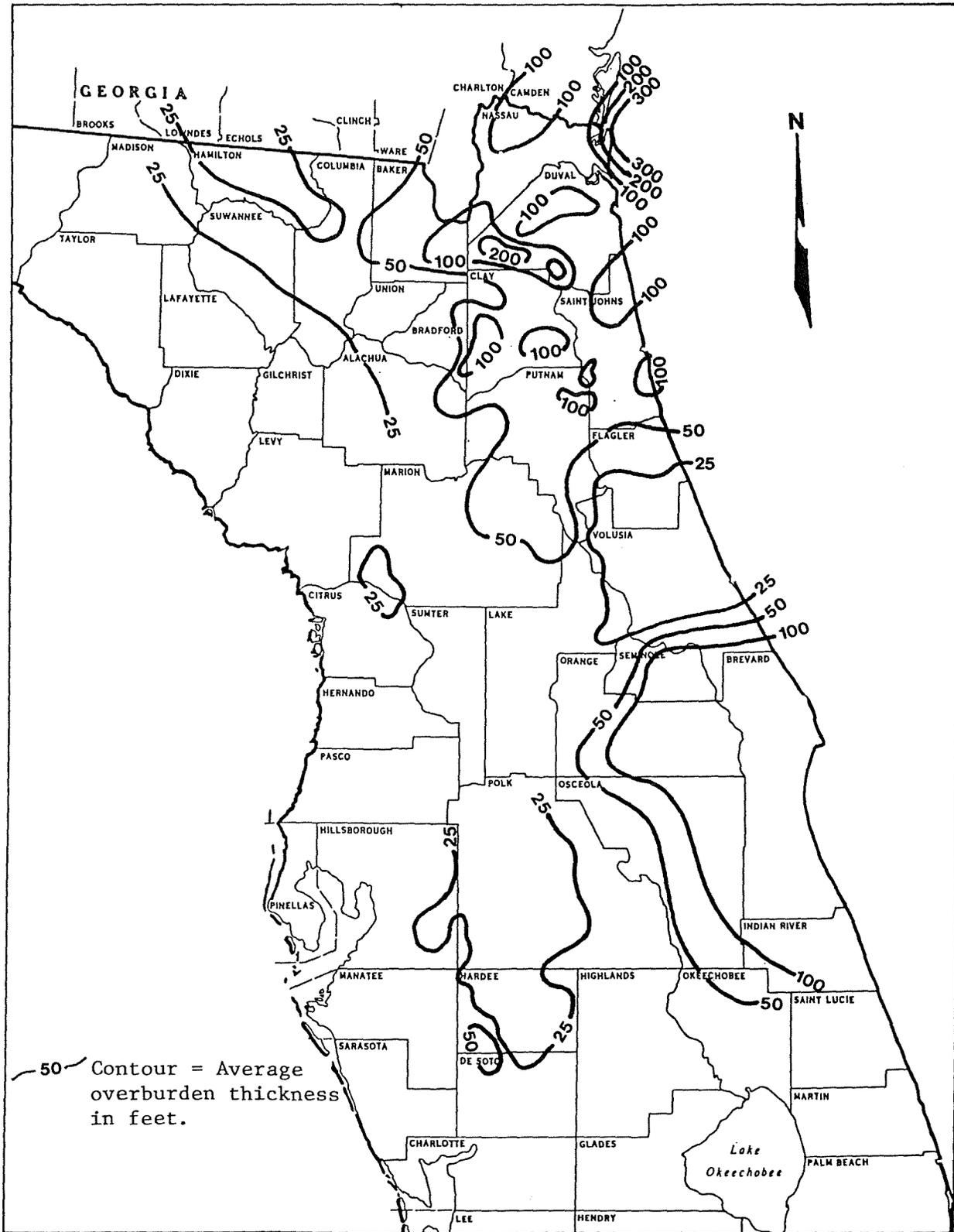
FIGURE 4. – Average overburden thickness.

The complex array of primary depositional environments and subsequent phases and modes of reworking have created a complex stratigraphic history for Florida phosphorite. The interacting phenomena, however, are the basis for the distribution pattern and quality of deposits across the state.

Production History

The U. S. Bureau of Mines Advance Summary for 1977 shows Florida's (inclusive of a single operation in North Carolina) beneficiated phosphate rock production was 40,551,000 metric tons (tonnes), or 91% of U. S. production and 35% of the total world production. This was an increase in production of 7% over the previous year and was less than apparent consumption[21]. This production, with the exception of a very small amount

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[21] U. S. Bureau of Mines: Advance Summary Phosphate Rock 1977, March 15, 1978. "Rock Demand Exceeds even 1974 Level", April 1978, British Sulphur Corporation Ltd., London England. pp. 5-6.

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of "soft rock", was entirely from land pebble phosphates in Polk, Hillsborough and Hamilton Counties. This area has increased its production rate over fifty percent in the past ten years, prior to which time it doubled each decade since 1940. Appendix G is the production record of phosphate rock in Florida since 1890.

Phosphate deposits in Florida were identified by early producers according to their physical appearance or location: "Hardrock," or phosphate-replaced limestone; "soft rock," which is clay debris of previous hardrock beneficiation; "river pebble," or phosphate nodules occurring in streams that have been winnowed from upstream or adjacent formations; and "land pebble," which describes phosphate extracted from ore occurring beneath the land surface (Bone Valley and Hawthorn formations). "Land pebble" statistics today include a small amount of scavenger production from coarse tailings ("debris") of initial beneficiation.

Figure 5 shows the phasing and duration of exploitation by type of occurrence; a brief accompanying description follows:
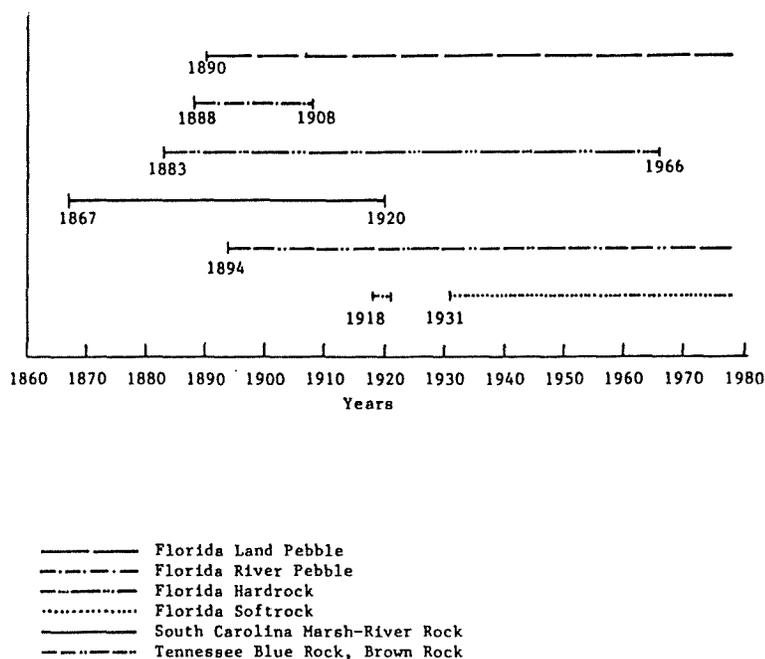
FIGURE 5. - Duration of mining phosphate in southeastern U.S.
(types of occurrence).

Prior to 1883, with the opening of a small quarry near Hawthorne, Florida, domestic production was confined to South Carolina, where it had been produced since 1867. "Hardrock" was first mined by men with picks, shovels, and wheelbarrows, followed by mule-drawn "scrapers" and wagons. Draglines were eventually used to remove the overburden as well as some of the ore. Beneficiation consisted of crushing, washing, and screening to recover a high grade pebble product. Hardrock deposits contain chert which, after crushing, was picked by hand from belts. By the 1950's hardrock mining had become modernized, but was eventually unable to compete with large volume land pebble operations. It dominated Florida production, however, until after the turn of the century and the period represents a colorful era of land-rushes, boom-towns and wild mineral speculation.

In 1888 laborers wading into streams with picks and crowbars began mining river pebble, primarily from the Peace River. This was quickly replaced, first by small steam shovels mounted on barges, then by eight to ten inch steam-driven centrifuge pumps mounted on barges with their wood-fired boilers. Figure 6 shows a typical dredge, barge-mounted washer and scow for the cleaned phosphate rock during this period. The Peace River was dredged until 1908. Fuel for boilers or rock drying was wood, used by one company at the rate of 600 cords per day, and cut locally or purchased from Hamilton Disston (the saw man) who had purchased 4,000,000 acres of land at $0.25/acre from the state for timber removal (much of this land was later discovered to be in the heart of the Bone Valley phosphates). Wood for fuel gradually became scarce, and was supplemented and replaced by coal.
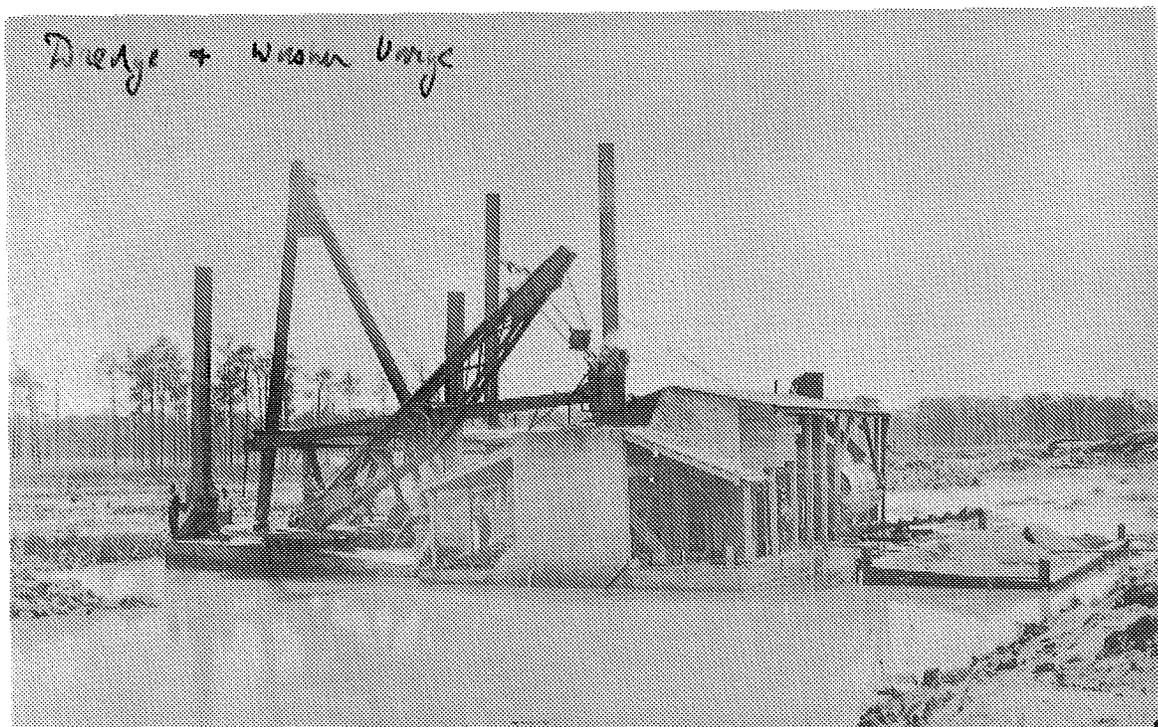
Dredge and washer barges with rock scow alongside.
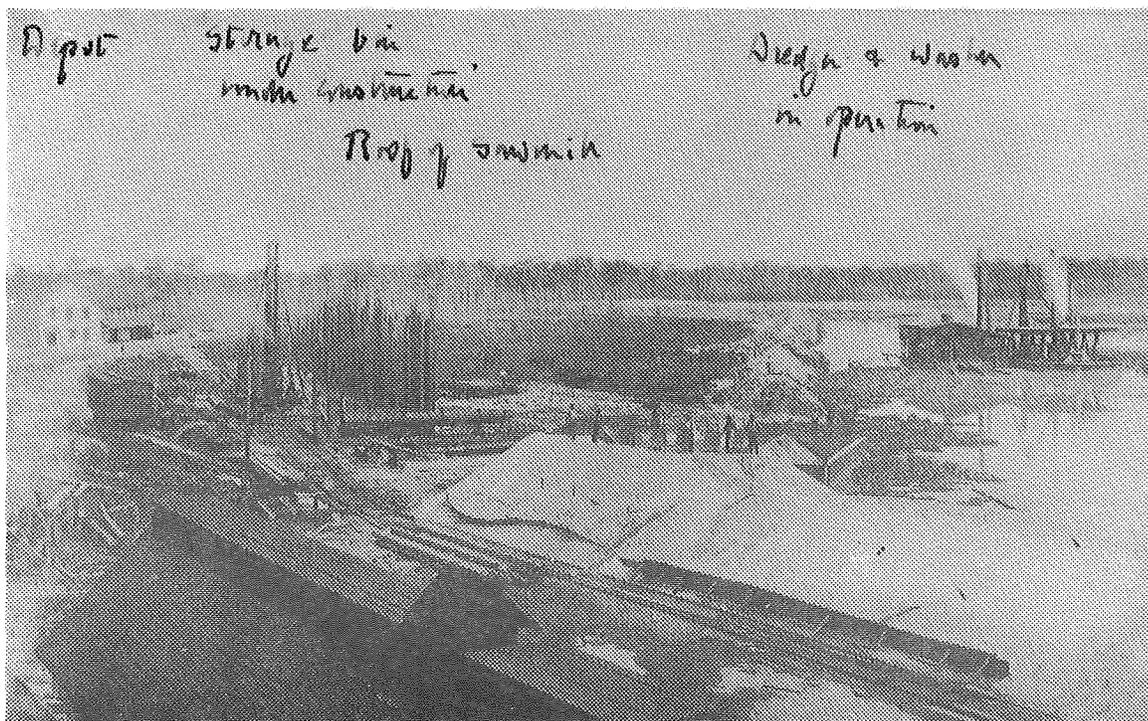
Panoramic view of operation. Wet rock storage in foreground, dredging in right background. Note steam boilers on barges. (NOTE: Notations on photos were written by photographer.)

FIGURE 6. – Early phosphate mining dredge operations.

It is difficult to pinpoint a specific year when phosphate was first mined in north Florida. Undoubtedly the hard rock prospectors prospected to the north and to the west of Tallahassee. River pebble was found and/or worked to some extent in Olustee Creek in Hamilton and Bradford Counties, Sopchoppy River in Wakulla County, Alapaha River in Hamilton County and Black Creek in Clay County. Mr. Wayne Thomas recalls that there were two mines near Jennings, Hamilton County, during the period of 1906-1912. Occidental brought onstream their modern mine facilities in 1965.

About 1907, a series of events changed the economics and method of mining phosphate:

- Most creeks and shallow river reserves had been dredged out.
- Land pebble miners were forced to do more overburden removal, which had been performed by mules and scrapers.
- Steam shovels were commonly accepted for mechanized earthmoving.
- Brooklyn Rapid Transit introduced an electrified mining system, powered by centralized steam turbine powerhouses.
- Prospecting discovered consistent, high grade land pebble strata.
- Second growth (cut over) timberland could be purchased from Hamilton Disston for $0.25/acre.

The mechanization coupled with resource discovery and other events made land pebble mining the dominant method of extraction, thereafter controlling economics not only locally, but ultimately world wide.

Initially, the overburden had been removed up to a depth of 15 to 20 feet by steam shovels linked to locomotives and dump cars. The operators used hydraulic giants which were supplied water by steam powered pumps to sluice the exposed upper pebble-bearing ore to a sump for pumping to a washer constructed nearby (usually central to a 200 acre tract). The water supply from wells was plentiful and not recirculated. The pebble was screened as the phosphate rock product and the "debris" consisting of phosphatic sand and clay discarded as waste.

Developments in the centrifugal pumps and the broadening use of electricity and diesel power continued to improve efficiency. Eventually, hydraulicking replaced steam shovels in many operations for overburden removal, later to be replaced by draglines. Of the innovations in the industry, however, two developments that began in the 1920's stand out as controlling the character and economics of all mining in the Florida field:

- Introduction of large (5-7 cubic yard buckets) movable draglines
- The flotation separation of finer phosphates with fatty acid reagents.

The larger draglines could more cheaply and efficiently remove over-burden (present day costs per yard of $0.05-0.10 versus pre-dragline era contracted cost of $0.25) and add volume or capacity to a single operation. By the 1930's, draglines initiated mining "on the hill" with a second follow-ing dragline placing the ore in a "well" on the adjacent unmined cut (high-wall). This method again enlarged mine capacity, increasing the matrix (ore)

available to the washer, simplifying equipment moves, and improving safety. By the early 1940's, larger "walking" draglines allowed a single machine to perform the overburden and ore removal function. The era of present day large capacity (30-60 cubic yard bucket) machines began with the purchase of a ± twenty yard Bucyrus Erie 1150-B. Pumping capability kept pace with earthmoving, and provided the capacity to absorb increasing production demands at low cost.

The development of washer debris (nominally 1.0-0.2 mm) recovery is probably the most important development in phosphate history; not only did it increase the product capacity of an individual mining operation by recovery of additional product from the ore, it also increased product grade (concentrate is usually higher in P_2O_5 than pebble), again lowered costs by volume considerations, and most importantly served to perhaps quadruple Florida's and the world's resources. Flotation allowed the entire ore section to be mined; previously only the upper pebble-rich zone of the Bone Valley was recovered. A pilot plant was placed in operation in 1927, and Phosphate Recovery Corporation began commercial operations in 1930.

A negative factor of these technical developments has been the more extensive landscape alterations in the past forty years due to dragline spoiling and the necessity for above-grade impoundment of clay from the increased ore section. These effects were compounded by the increased volume or mining rate such efficiencies effected and the market dictated. More rock production has occurred in the past decade than in the previous four.

Figure 7 illustrates the production from the various phosphate resources previously described at the turn of the century, and the dominance of land pebble mining after 1908. The rich deposits and evolving technology that allowed increased production at low cost has kept Florida as the largest producer of phosphate rock in the world. Until recently, Florida rock established by virtue of its extremely low cost the basis for world rock prices. The price of phosphate rock in constant dollars remained almost unchanged for the period 1954-1974[22] ($9.00-10.00 per

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22/ Stowasser, W. F. Phosphate Rock in Minerals Facts and Problems. BuMines Bull. 667, 1975. pp. 819-834.

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short ton) excepting a sharp decrease in prices 1968-1973 due to over-supply. In 1975, however, the price doubled due to domestic and world demand, and Moroccan influence on export prices. During 1977, however, the market had readjusted to $13.00-15.00, short ton 1975 basis[23]. The price increase

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23/ Stowasser, W. F. Phosphate - 1977, Bureau of Mines Mineral Commodity Profile, May 1977.
_____, Phosphate Rock - 1977, Advance Summary, U. S. Bureau of Mines, March 15, 1978.
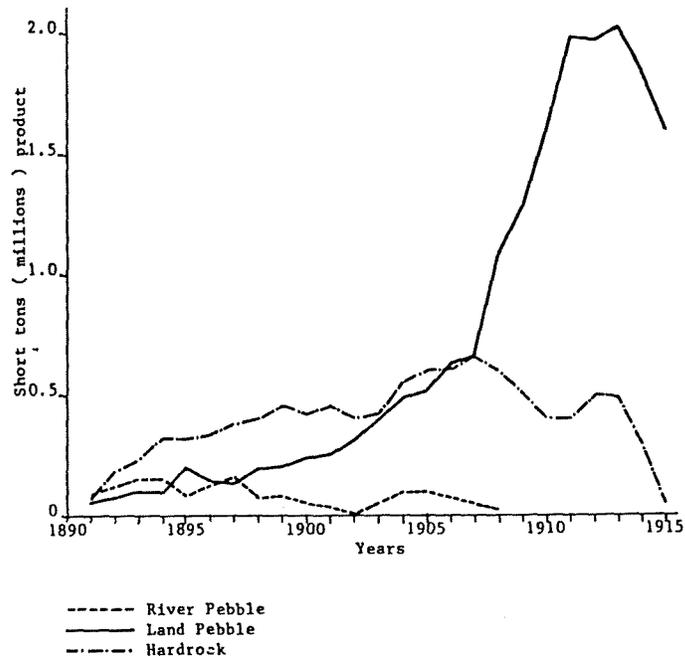
FIGURE 7. - Production of phosphate rock product, 1891-1915.

was timely and fortuitous for the industry, which concurrently had dramatic cost escalation due to energy, labor, tax and capital investment increases. Prior to 1908, mining was apparently more profitable. Rock prices at the turn of the century ranged about $17.00 per short ton with very little capital investment. At one time 400 companies operated statewide. By 1909 there were only 20 companies operating in the hardrock field and fourteen in the land pebble (Central Florida) district. These operations, however, were very labor intensive; 7,600 employees in 1909 were required to produce less than two million short tons of rock, as compared to a similar number today producing twenty times more. The mechanization and evolving technology increased capital requirements (thus reducing the number of operating companies), lowered labor requirements, and increased mining capability at lower unit costs.

Appendix B is a chronology of important events for the period 1837-1942 by Dr. A. T. Cole as a contribution to this study. Since that time most technical applications have been refinement, improvement, or enlargement of previously developed processes and equipment. Specific improvements worthy of mention are improvements in recovery through feed sizing and

improved reagentization, the use of cyclones for desliming, and recent innovations in waste disposal and land reclamation (discussed later in this report).

The technologic achievements, availability of resources, and rich phosphate deposits have allowed Florida to maintain world leadership for seventy years. The potential aspects for maintaining this position are discussed later in the report. Appendix G lists Florida phosphate rock production by year since 1888. Districts are not designated for reasons of confidentiality, and North Carolina production is included with Florida's since 1965 for the same reason.

DEPOSIT CHARACTERIZATION BY DISTRICT

The phosphate producing districts of Florida have been identified under more than one name in previous literature. The names most commonly used at present by those working in the state are shown in figure 8.

Central Florida Phosphate District: This includes not only the presently producing land pebble area in southwestern Polk and southeastern Hillsborough Counties, but newly developed prospects in DeSoto, Hardee, and Manatee Counties. The latter counties are grouped locally and referred to as the "South Florida District" which is a confusing but now commonly used term.

Northern Florida Phosphate District: This area is mainly identified with production in Hamilton County, and extends southward to known deposits in Columbia, Baker, Union, Bradford, and Alachua Counties.

Hardrock Phosphate District: This district includes the narrow elongated band of past production from "hardrock" phosphate in Hernando, Citrus, Levy, Marion, and Gilchrist Counties, but may also include a long identified out-lier or extension in Lafayette County known as the "Steinhatchee district".

These districts are all characterized by distinct differences in product grade and/or mining and metallurgical properties. Deposits within each district have in common similar properties or characteristics, primarily a result of a common mode of origin or subsequent physical or chemical alteration.

In addition to the above described districts, data was gathered for deposits occurring on the eastern coast of Florida. The data was gathered by a prospecting program jointly sponsored by the State of Florida (drilling, gamma logging) and the U. S. Bureau of Mines (core logging, metallurgical analysis) supplemented by correlation with gamma ray logs supplied by the U. S. Geological Survey and the St. Johns River Water Management District. In addition, some prospect borings were supplied for the area by an active mining company. Although control is sparse, sufficient data points were available to correlate the phosphorite. Metallurgical analyses from the prospecting provided agreed with the new metallurgical data derived from nine holes drilled by the State. The resulting information is sufficient to recognize deposits of unique characteristics; it has, therefore, been identified in figure 8 as the Northeast and Southeast Florida phosphate districts. The two districts are similar and can be combined as the "East Coast district"; they were separately delineated because of an apparent absence of ore-bearing strata over the Sanford High centering in Flagler and Volusia Counties.

The characteristic deposit data for each district is tabulated below:
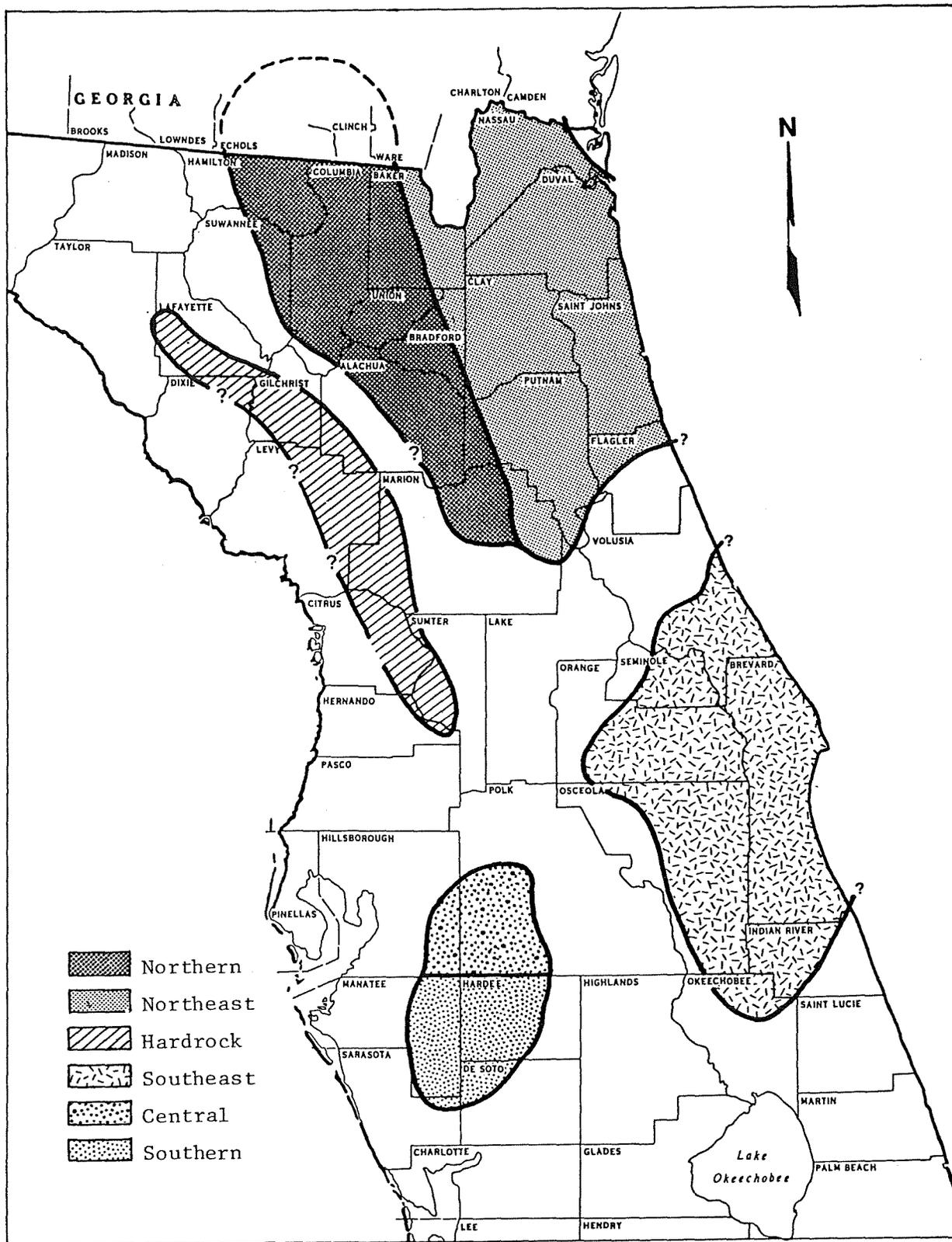
FIGURE 8. - Identified Florida phosphate resource districts.

TABLE 1. - Deposit characteristics of Florida phosphate districts

	Central Florida	South Florida	Northern Florida	Hardrock	Northeast & Southeast "East Coast"
Overburden Thickness feet.................	20-30	20-40	20-50	10-?	50-150
Ore Zone Thickness feet.................	15-25	15-35	10-25	5-30	5-50
Pebble Percent Product..............	20-60	10-25	10-20	60-100	0
Percent BPL............	68-72	66-69	66-70	72-78	62-65
Percent MgO............	<0.5	0.8	0.75	NA	0.9-2.0
Percent U_3O_8 of Product..............	0.012	0.009	0.008	0.010	NA
Percent F..............	2.5-3.5	2.6-3.5	3.0-4.0	NA	NA

NA - Not available

Overburden Thickness

Overburden above the phosphorite ore zone has been mapped on figure 4 in the depositional history section. The isopach is regional in scale and represents _average_ overburden thickness in deposits. As with other maps to follow, it does not identify the local irregularities common to most deposits.

Deposits in the Central, the northeastern portion of the "South" and the Northern districts have average overburden of less than 25 feet. Overburden thickness southwest of the "South" district increases. The western "boundary" of the Hardrock district has actually been previously delineated by deeper overburden. The boundary between the Northern and "Northeast" districts has been placed near the 50 foot overburden contour, which also was used to delineate the western boundary of the "Southeast" district. The 50 foot contour selection was not selected as a mining barrier (as with the western limit of the Hardrock district), but rather delineates ore to the east which has a grade of about 65% BPL (29.7% P_2O_5), an increase in MgO percent of product to above 0.75%, a loss of most pebble of sufficient quality to be of potential product value (<50% BPL or 23% P_2O_5), and most obviously, eastward of which local structure becomes more sharply defined.

Ore Zone Thickness

The ore zone thickness contoured on figure 9 again represents averages for identified deposits. In non-producing areas, a thickness is difficult to establish because of the inexact definition of what will constitute an economic ore at the time of extraction. In the Eastern district thickness varies sharply with position on structure, as does ore quality. As in North Carolina
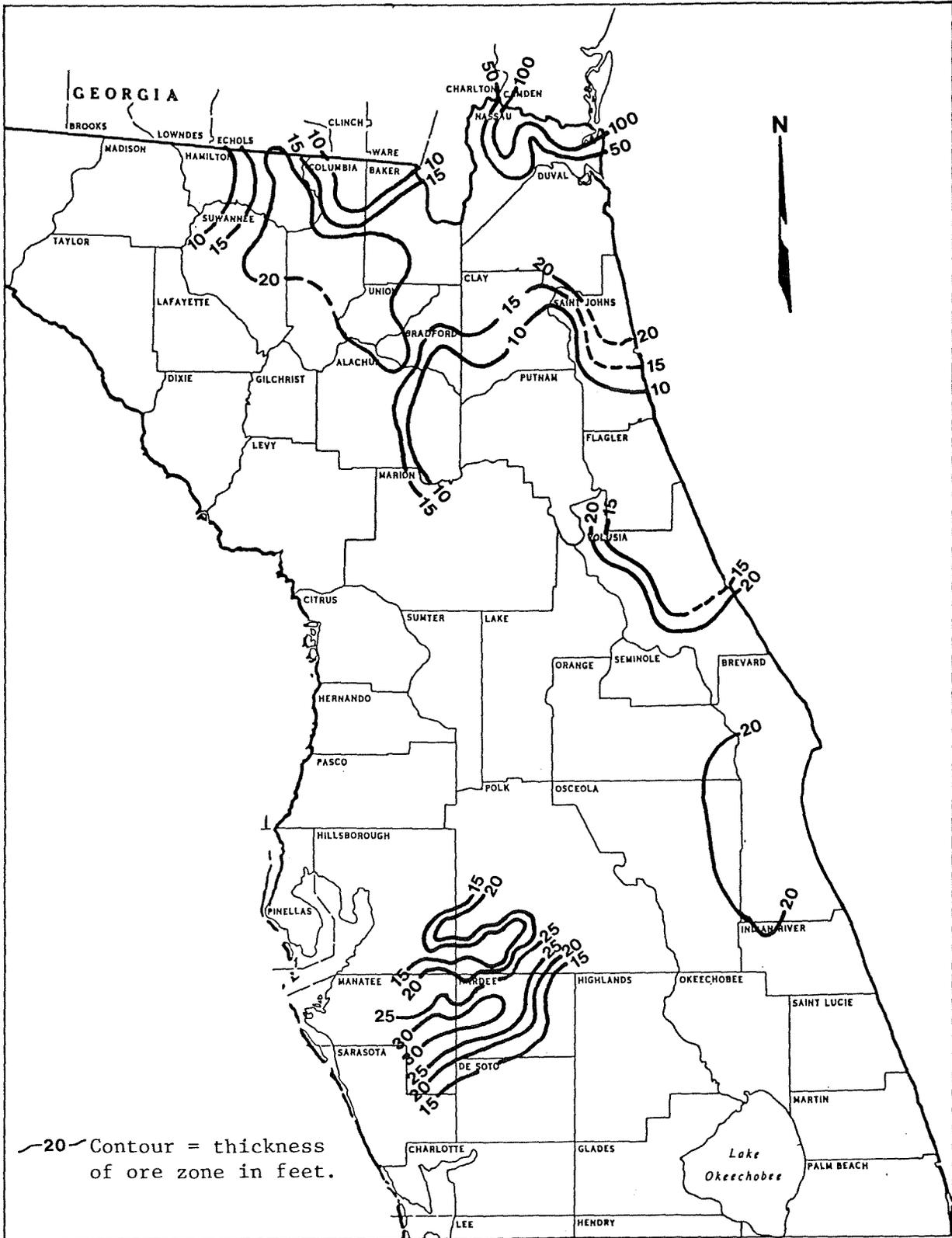
FIGURE 9. - Ore zone thickness.

and eastern Georgia, downdip the phosphate concentration remains relatively constant and is diluted with clay, limestone, and sand constituents.

The two producing areas have average ore zones of similar thickness, ranging from 15-20 feet. Note that in the Central/South Florida districts, a 15 foot thick zone in the center of the producing area is surrounded by 20 foot thick deposits, which further thicken southward to a northeast-southwest trending trough in Manatee and Hardee Counties; the ore again thins southward into southern Hardee and DeSoto Counties.

Fifteen to twenty feet approaches a maximum-average thickness for the Lower Bone Valley formation, the primary producing unit in central Florida. Thicker zones southward and southeastward in central Florida, and eastward in northern Florida, are of usually lower phosphate concentration, much of it Hawthorn age. Strandline position was an important factor in the reworking and secondary enrichment of phosphorites.

Pebble Percent of Product

The production history section of the report discussed the implementation of froth flotation in the 1930's as a means of recovering phosphate from previous washer debris. Prior to this time phosphate mining and beneficiation in river pebble, hardrock, and land pebble had consisted of recovering only coarser (+1.0 mm) material. The froth flotation process not only increased the capacity and reserves of existing mines, but established a means of recovering fine-grained ores. The flotation product, due to lower insoluble content, is generally higher grade than the pebble. The pebble constituent, however, usually contributes significantly to total ore concentration and the washing/screening recovery process is inexpensive as compared to flotation. Thus, the pebble to concentrate ratio - or pebble percent of product - is a measure of ore desirability. Figure 10 shows that the highest concentration of pebble is in the Central Florida and Hardrock districts.

The Hardrock 100% contour is actually misleading in that there is a recoverable sand-size fraction, but it has not yet been successfully commercially recovered to any large extent. The cost of installing a downstream flotation process for hardrock screening has heretofore been considered prohibitive. This may not necessarily continue to be the case, but the economics relative to capital investment for the small scattered hardrock deposits have been discouraging.

In the Central district, the coincidence with the thinner ore in the previous figure is evidence of pebble concentration by winnowing in higher energy environments related to structural highs. Downdip the ore zone thickens, but becomes finer grained.

In the Northern district, a similar winnowing phenomenon is apparently evident in the strandline position of more concentrated deposits in Hamilton, Columbia, and northern Alachua counties. Although transgressive/regressive erosional cycles are evident, the depositional environment was not as conducive to pebble concentration as in central Florida.
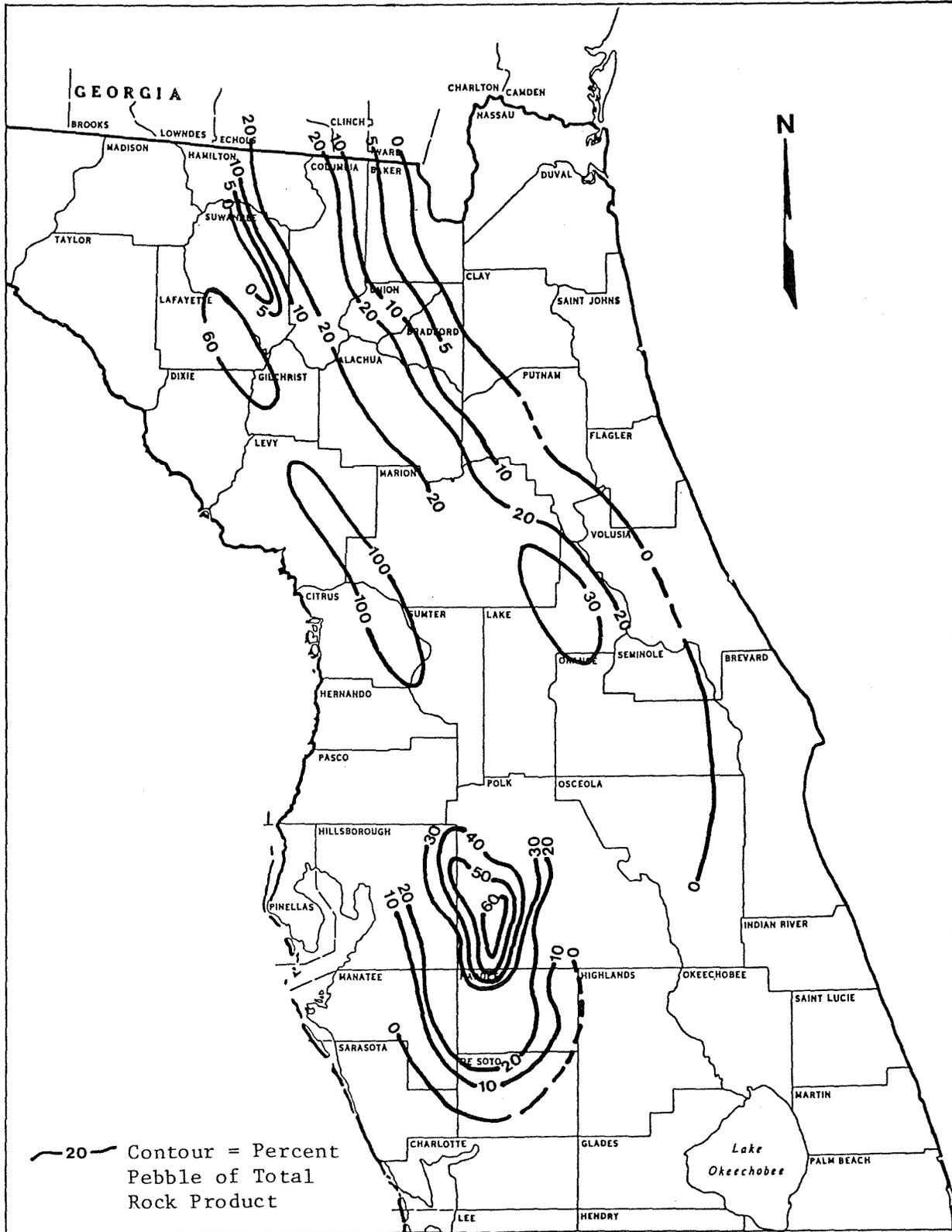
FIGURE 10. – Percent pebble of total rock product.

Downdip, pebble becomes lower in P_2O_5 content and ultimately contaminated with limestone, dolomite crystals or rock fragments. Figure 10 represents the pebble percent of total product, which includes only pebble of salable grade or suitable for potential upgrading (criteria designation was >50% BPL, or 23% P_2O_5). Most pebble included would require little upgrading or could be blended with higher grade concentrate. The zero contour on the figure delineates the downdip limit of salvageable pebble, with most +1.0 mm material being primarily phosphatic limestone or dolomite; it typically contains $\pm$30% BPL (14% P_2O_5).

Recovery of some lower grade pebble product from land pebble deposits is presently being carried out at Occidental in Hamilton County where the +1 mm phosphate – if of acceptable grade – is ground and enters the flotation circuit. Projected developments in the South district are considering various recovery or upgrading processes.

Product Grade

The grade of the beneficiated ore is dependent on the success and extent of beneficiating the inherent phosphate grade (% P_2O_5) and the percent of the lower grade pebble constituent. Figure 11 reports the average value of deposit product in BPL units. BPL or Bone Phosphate of Lime units were selected because of the familiarity with the term in Florida mining and marketing (% BPL = P_2O_5 x 2.185). Higher (+70% BPL) product is present in substantial amounts in the Central Florida and Hardrock districts, although the Northern district has identified significant deposits averaging near this grade. The map isogram, in fact, is somewhat misleading in that it shows a larger area in the Northern district than in the Central within the 70% BPL contour. The Central district, however, has higher grade concentrates diluted by substantial pebble product which is lower in BPL. As the map illustrates, moving each way but southward from the Central pebble area shows an increase in total product grade from the influence of increased product constituency of higher grade concentrate. The highest grade ore remaining is primarily located in the eastern portion of the district near the Peace River.

It is presumed that higher grade product is at least a partial result of enrichment due to post-depositional leaching from downward water percolation. Some research has noted the coincidence of higher grade product to sink activity or karst terrain induced on the limestone bedrock in both the Hardrock and Central Florida districts.

A uniform decline in product grade is apparent downdip from strandline deposits, primarily due to higher calcium content (CaO/P_2O_5 ratio) rather than insoluble content. East Coast deposition and concentration, although definitely structure related, was under a different depositional environment than Central or North Florida. It may not be of exact equivalent age. The ore varies distinctly in richness depending on structural position, is fine grained, more dolomitic, and concentrates (adjusted to 5.0% insoluble) range from 62-65% BPL. These grades show little subsequent enrichment, apparently a result of subsidence, and little vertical hydraulic head subsequent to deposition.
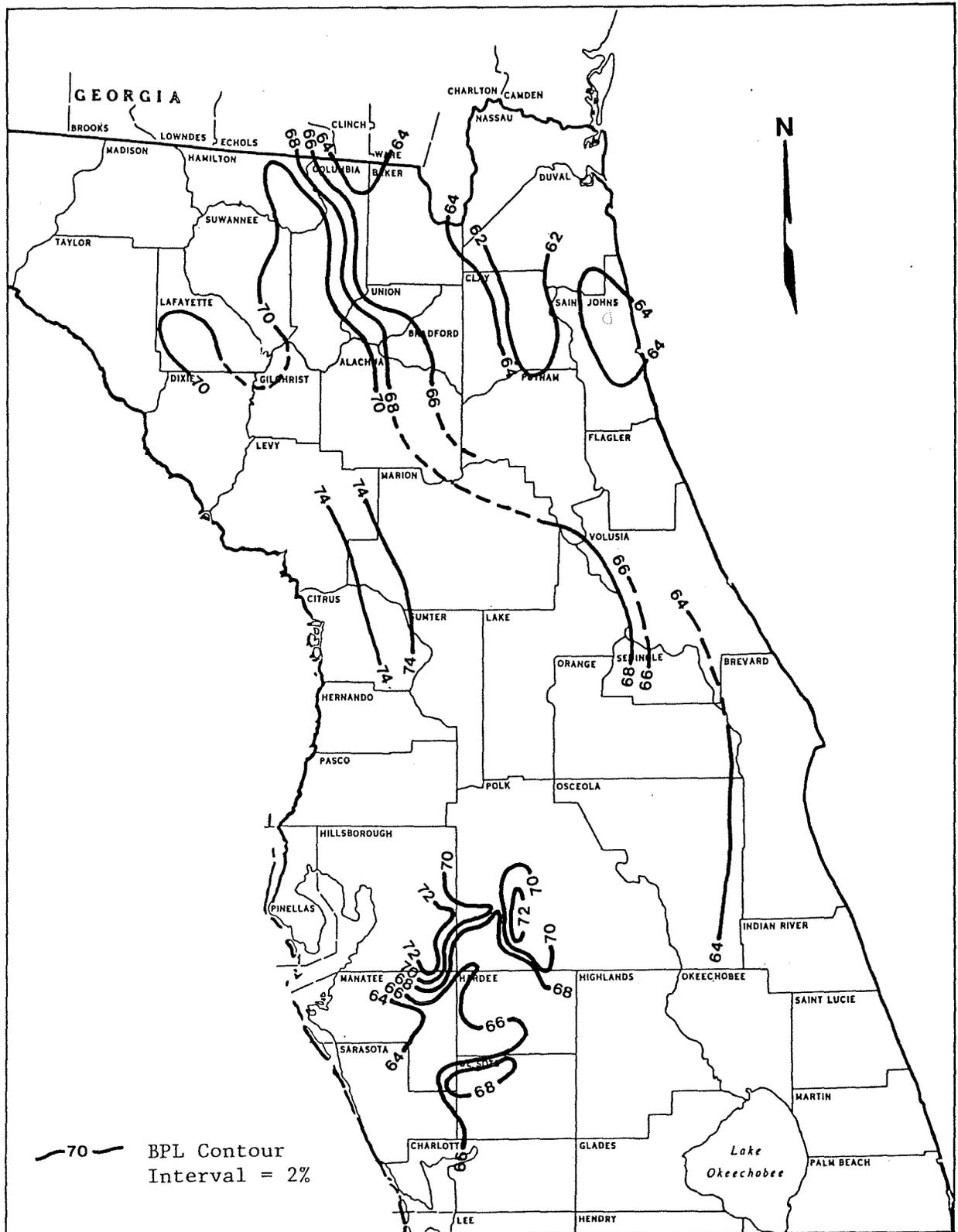
FIGURE 11. – Percent BPL of product.

All deposits (excepting debris) fall into one of the described districts and depositional patterns, excepting a single deposit in northeastern Lake County. This "outlier" resembles Central Florida in ore constituency, but of somewhat lower grade. It is poorly defined from the information available.

Magnesium Content

MgO is a contaminant in phosphate rock that presents process difficulties in the various steps of fertilizer manufacture. Its occurrence and possible potential for removal from rock in the beneficiation step are discussed later in this report. The MgO levels shown on figure 12 are the content of phosphate rock routinely concentrated. Because MgO has been routinely analyzed from prospecting only in the past five years, data coverage of all districts is incomplete. The figure is based on actual analytical data, however, and is a reasonably accurate depiction of MgO content in the various districts or trends. As expected, MgO content increases downdip either as a result of primary dolomite deposition, inclusion of MgO in the phosphate lattice, or lack of exposure to post-depositional leaching.

Uranium Content

Uranium analysis for most deposits is either scanty or closely held; little deposit-specific analytical information was offered to the study. The values shown in table 1 are for the Hardrock and Central districts derived from current literature; South Florida values are a result of those offered to the study by several companies developing new deposits. The East Coast and North Florida data are not available to a reliable extent at this time; they are, however, expected to be comparable to those of South Florida if related to strandline position, grade, pebble content, etc.

Fluorine Content

Table 1 shows the range of fluorine content for phosphate rock product. The rock is mineralogically a fluor-apatite, and the constituency of the mineral is rather consistent. The fluorine content of total recoverable phosphate rock in the southeastern United States is the largest known domestically available resource of this commodity.

Other Deposits

A final designation in addition to those of the primary ores are debris deposits, or wastes of previous mining-beneficiation activities. These deposits are being mined as scavenger operations in the Central Florida district by flotation of previous washer debris or flotation tailings for concentrate production, and in the Hardrock district by mining of "softrock", the colloidal clay fraction of previous ore washing. Colloidal clay in this district is usually in excess of 50% BPL (23% P_2O_5) and is used on a small scale but successfully for direct application fertilizer, special organic fertilizer mixers and for forestry. Both of these operations and their resource potential are discussed in more detail later in this report.
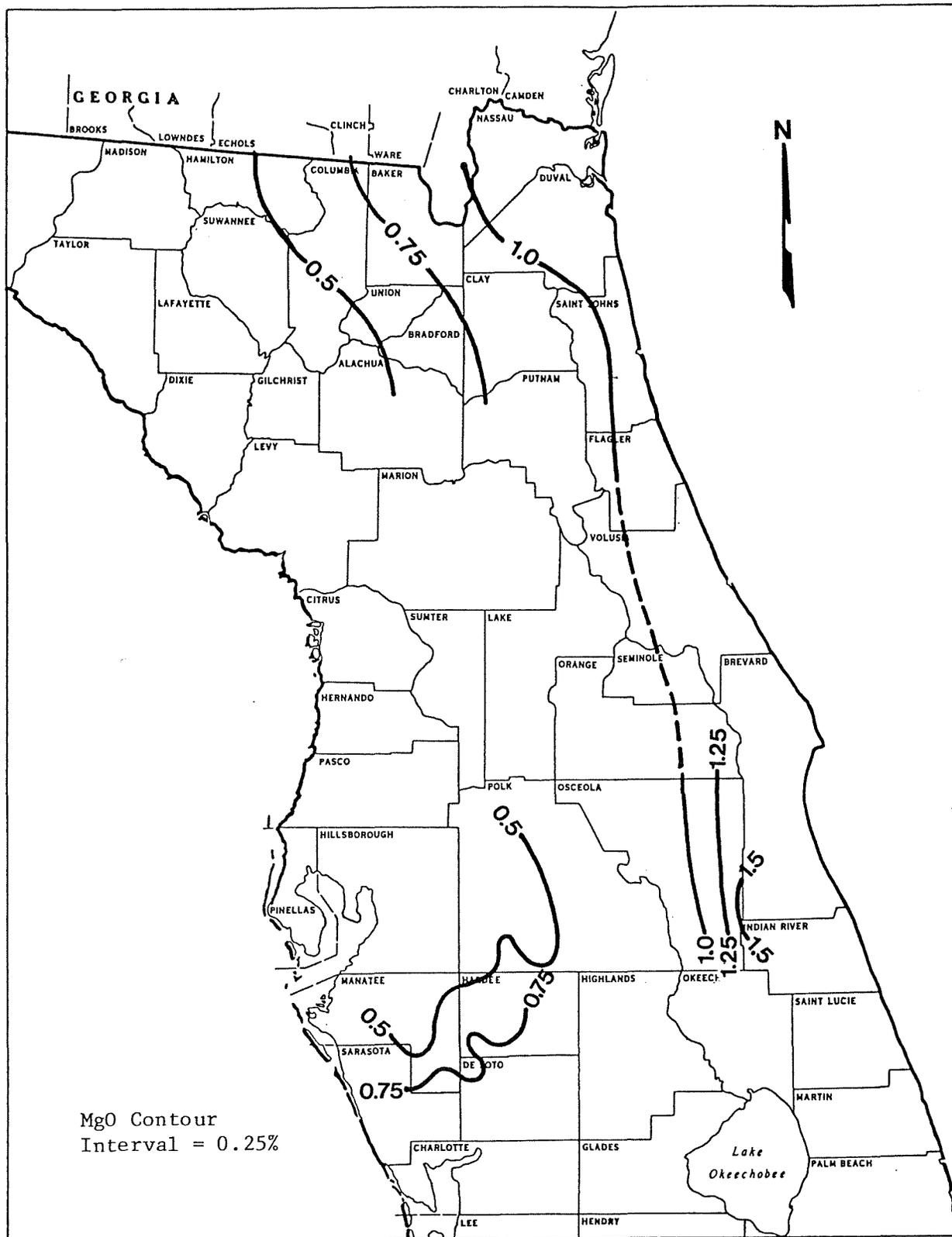
FIGURE 12. - Percent MgO of product.

MINING AND BENEFICIATION

Mining

Mining of phosphate ore in Florida is presently conducted utilizing strip mining methods. The nature of these mostly unconsolidated sedimentary deposits have lent themselves to open pit mining, consisting of stripping away the overburden to expose the ore for recovery.

The mining process is briefly described as follows: each dragline digs a series of parallel cuts several hundred to several thousand feet in length and 200-300 feet wide as it traverses the mining unit. The overburden is cast into the previously mined cut and the underlying matrix (ore) is exposed. The matrix (ore) is then mined and transferred to a slurry pit located above ground within reach of the dragline. In the slurry pit, large water guns (monitors) deliver 10,000-12,000 gallons of water per minute at about 200 psi to break down the friable ore into a slurry for pumping to the central washing unit in the mill area. Each dragline usually has its own associated pumping system. The ore is not to be completely recovered due to the irregularity of the contacts with the overburden or underlying bedrock and irregularity of the ore itself. Upper and lower contact losses can be significant. It is estimated that 85-90% of ore is physically recovered from the cut.

Shallow total mining depths of less than 60 feet and favorable overburden to ore thickness ratios (in the range of 1:1), have made dragline use for both stripping and ore extraction the standard method of mining. In more recent years total depths have increased and overburden to matrix ratios have become less favorable, placing more demand on total digging capacity and greater reach (boom length) to allow sidecast spoiling of the overburden without encroachment on the ore. Some of the projected operations in the South-Central district will have average mining depths of 75 feet with maximum depths up to 110 feet.

The ratio of overburden to ore for a deposit determines to a large degree the total earthmoving requirement for the required production rate. The following overburden to matrix ratios (yards overburden:yards matrix) are typical of deposits for each of the listed districts. Individual deposits, and of source areas within a deposit may vary from the ratios shown:

District	Overburden yards/matrix yards
Central Florida	1.0-1.5:1
"South Florida"	0.5-1.5:1
Northern Florida	1.5-3.0:1
Hardrock	0.5-2.0:1
"East Coast"	4.0-8.0:1

Mining depths for draglines have, of course, been greatly extended by the development of very large, long-boom machines used for coal stripping. The problem with machine specification for a specific ore body, however, cannot always be solved simply by using a dragline with excess capacity. The key factors determining machine size and reach are: 1) soil bearing capacity, 2) highwall stability, 3) overburden to matrix ratio, 4) total depth, and 5) other considerations such as spoil stability, pit water problems, etc.

Draglines are operated by a crew of two or three men. Walking speeds of approximately 500 feet per hour are attained by "steps" of seven or more feet. These machines are powered by electricity at 4,160 volts (7,200 volts for newer models) which is converted from AC to DC by large synchronous motor generator sets. The DC motors are ideally suited for powering and controlling the normal machine cycles of dragging, hoisting, and swinging.
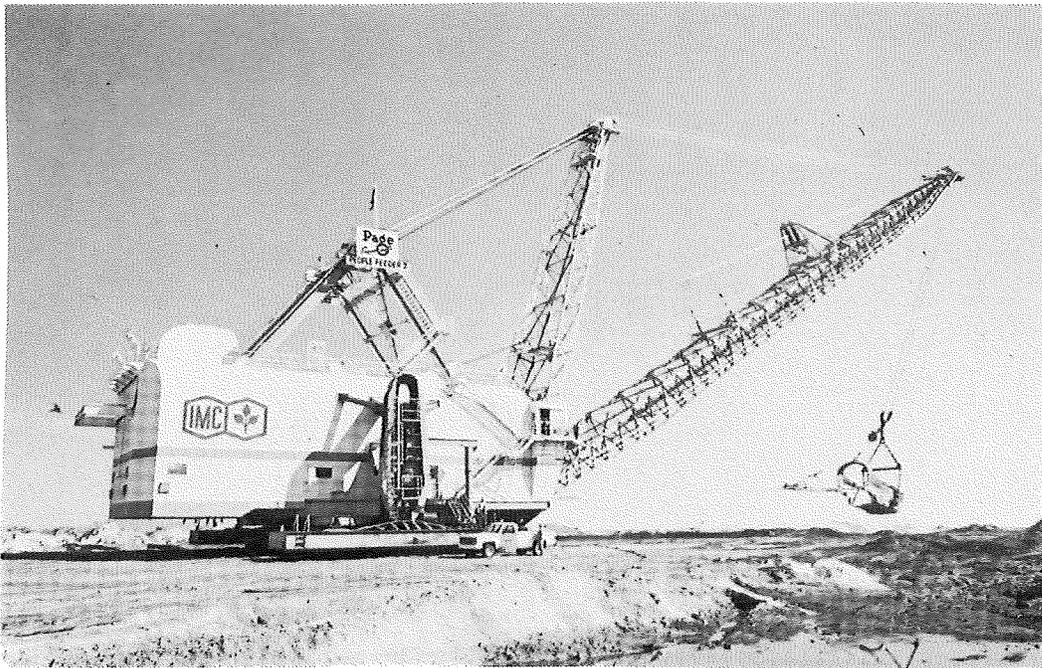
FIGURE 13. - Typical dragline.

One dragline may be used for stripping overburden only, with another digging ore, or may alternate between stripping for one or more shifts and then mining the ore which has been exposed. In cases where overburden to matrix ratios are favorable, one machine may alternate digging and side-casting overburden and delivering ore to the slurry well. The procedure used depends on the specific conditions of the ore deposit.

Texasgulf in North Carolina has employed a successful method of stripping the top 40 feet of overburden with dredges and pumping this spoil away for reclamation of mined out areas. The dredge pit is drained and dried. The large draglines work on the stripped bench and mine to a depth of 100 feet (total pit depth 140 feet), very successfully obtaining good recoveries and production. See figure 14.
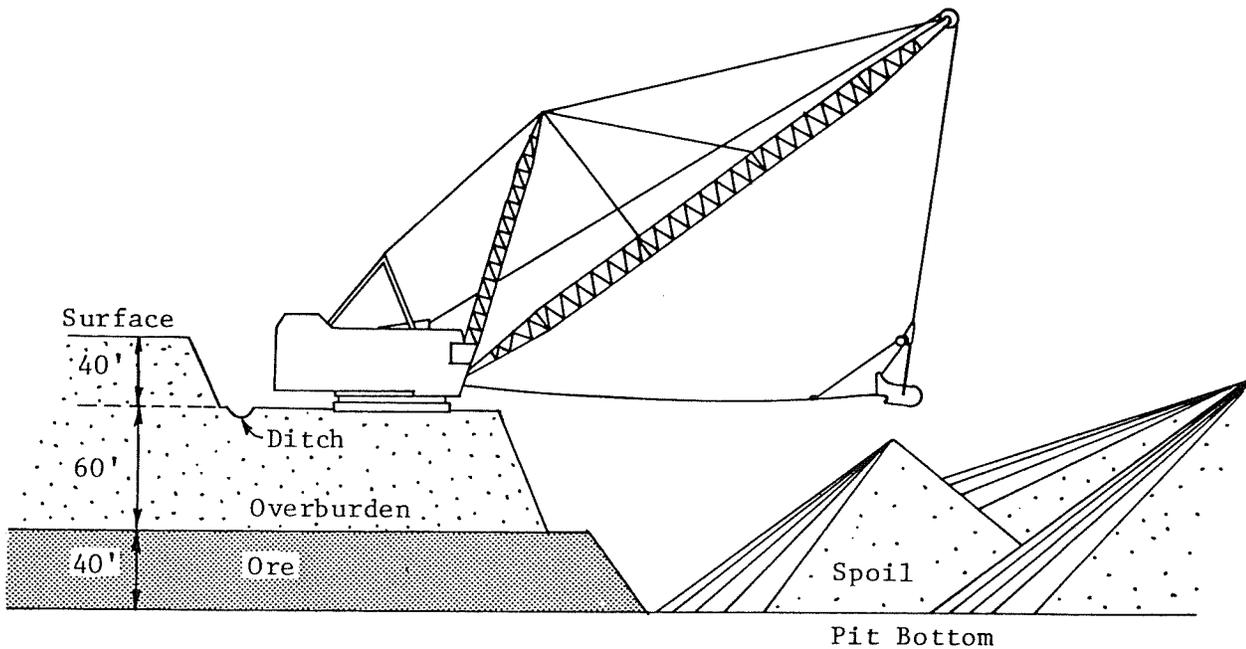
FIGURE 14. — Bench operation for deep overburden.

Florida earthmoving requirements do not immediately face those described for Texasgulf; however, poor bank and spoil stability, greater total depths, and leaner ore will lead to the use of machines with larger capacity and reach in the future. The standard size machine being purchased in the industry today is 40-45 cubic yard bucket capacity with 220 feet of reach, costing $7-8.5 million. The next increment in dragline size increases to a 50-60 yard bucket capacity and 300 feet of reach, and costs about $15 million per unit.

The extremely high capital cost of these draglines, plus bank and ground stability problems, total depth, etc., have prompted reexamination of the standard earthmoving methods. Beker Industries has announced their intention to use large cutter head dredges for stripping and mining in their mine planned in Manatee County, Florida. There are advantages to dredges for

this type of mining such as: 1) lower initial investment, 2) less effect
on surface aquifer (water table) if lifts are not required (that is, drops
in water level to facilitate mining deeper with the dredge), 3) continuous
placement of overburden at end point (reclaimed location, and 4) other
advantages such as mine appearance, etc.
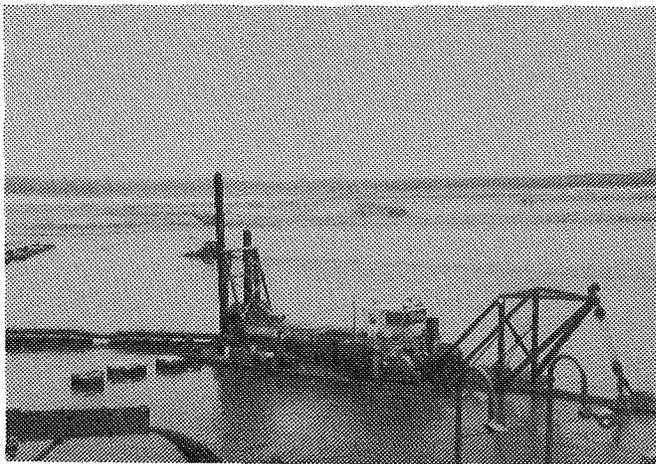
FIGURE 15. - Dredging operation.

Typically the dredging operation consists of dredges equipped with
large (+30 inch) centrifugal pumps pumping the slurry excavated by cutter-
heads extended below the surface. Figure 15 is a photo of a typical
dredging operation. Figure 16 is a sketch prepared by Beker Phosphate
Corporation to illustrate the mining method proposed for their Manatee Mine[24].

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[24] Beker Phosphate Corporation, 1974, Application for Development Approval
of a Development of Regional Impact under Section 380.06(6) Florida Statutes,
Appendix 11, Bradenton, Florida.

The overburden is excavated by the large overburden dredge. The spoil is
pumped through pipelines to land reclamation areas behind the mining
operation. The matrix or ore mining dredge follows the overburden dredge
by several hundred feet. The exposed ore body is removed and hydraulically
transported through pipelines and a series of booster pumps to the washer
(processing plant).
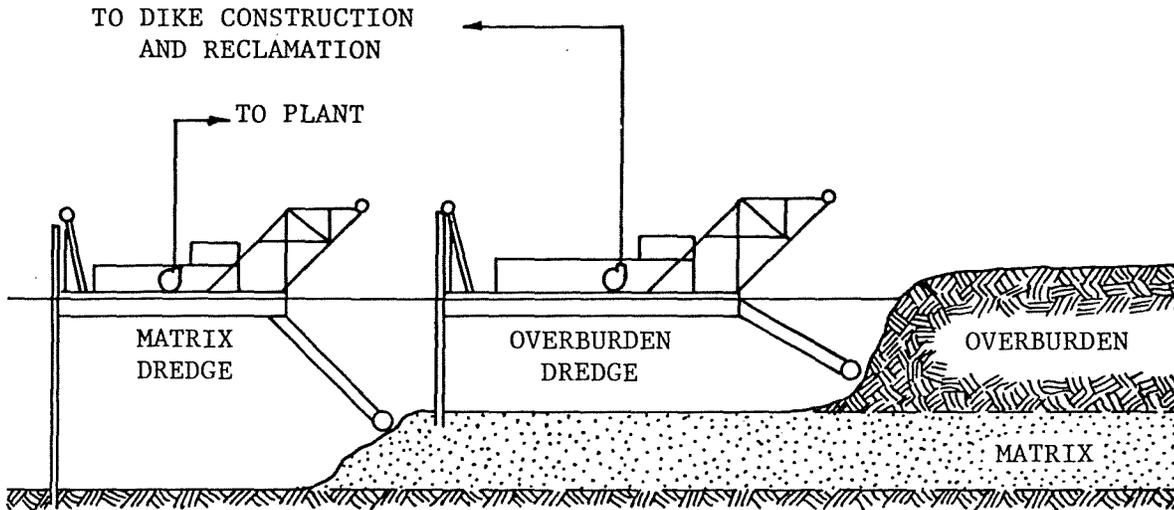
FIGURE 16.—Typical dredging operation.

Without specific knowledge of the ore body and local conditions, it is difficult to compare the expected results of dredges to draglines; however, some other major considerations are:

- The cost of dredging overburden and pumping it some distance from the active cut is probably $0.35-0.40 per cu yd/mile versus $0.05-0.08 cubic yard for draglines which move the overburden only 150-300 feet. The cost of reclamation, however, is offset to some degree by dredge placed fill, and the exact cost difference must be ascertained for each ore body and mine plan.

- If the overburden contains clays, secondary slimes may be produced by hydraulic transportation, causing disposal problems and increasing water consumption. The Texasgulf experience has been good in this area and their stripped overburden does contain clays. Still, this factor must be considered.

- A major concern has been identification and adherence to upper and lower ore contacts. Irregular ore zones are the rule in Florida and transitional contacts frequently require an experienced geologist for proper mining control, without which mine recovery may suffer substantially, or conversely, the ore pumped to the plant will be diluted with the adjacent overburden and/or pit bottom material. Once contacts are identified, the operator uses visual control to maintain them.

  Dredging depths can be reasonably controlled but ore undulation over short distances may cause problems, and are almost certain to require closer prospect control. Dragline mine recovery varies almost directly with: 1) ore zone thickness and 2) the success of pit seepage control. Recoveries range from below 80% to above 90% and probably average 85%. No production experience for dredges has been developed which applies to the present situation; however, experience and development of new methods will probably be required for dredges to achieve high recoveries. This is not to imply that dragline mine recoveries have been or will continue to be satisfactory. New methods need to be developed for draglines, but visual control in conjunction with actual in-the-pit sampling are advantages of dragline mining which will be difficult to match. Development of better pit dewatering equipment or methods will be needed for optimization of recovery in many areas.

- The first phase of ore beneficiation performed consists of hydraulic gunning and coarse screening of rocks and roots by a grizzly. This must be performed at the washer when a dredge is employed, and the debris hauled away for disposal. In dragline operations, this initial rejection occurs in the field.

- The slurry pit near draglines loses ore from abandonment or rejection accompanying the roots and rocks. These losses would not occur in dredging.

It is clear that trade-offs are involved in mining methods, and this can only be properly evaluated in respect to specific applications. The success and cost experience of dragline strip mining will continue to make it a popular and justifiable selection. Improvements in pit control, recovery, etc., however, are still in order.

Wheel excavators have not been applied for stripping or mining in Florida; however, North Carolina Phosphate has announced their intention to employ wheels for mining their North Carolina deposit adjacent to Texasgulf. These very high capacity machines, in conjunction with spoil stackers, are planned to handle from 30 to 45 feet of overburden while the remainder of the overburden and the ore is to be mined by draglines.

Experimental work on in situ slurrying with high pressure water injected
through drill holes has been conducted and will continue to receive attention.
Ore recovery, ground subsidence, and other problems have been identified.
This mining technique may have specific applications, such as in smaller ore
bodies (lower capital) or to deeper environmentally sensitive deposits. In
all cases for this study, for cost identification draglines were considered as
the prime mover (Beker excepted). Draglines required ranged in size from
machines carrying 12 cubic yard buckets with 175 foot booms to large machines
with 55 cubic yard buckets and 300 foot booms.

Ore Transportation

To fully integrate the conventional slurry ore transportation system, it
is essential to consider that the slurry pit ("well") actually performs the
first steps in beneficiation of the ore; the ore is partially disaggregated,
and screened through a grizzly to remove rocks and debris. It is further
"scrubbed" in the pipeline to the mill. Figure 17 is a photo of the slurry
pit with the monitors in the foreground.
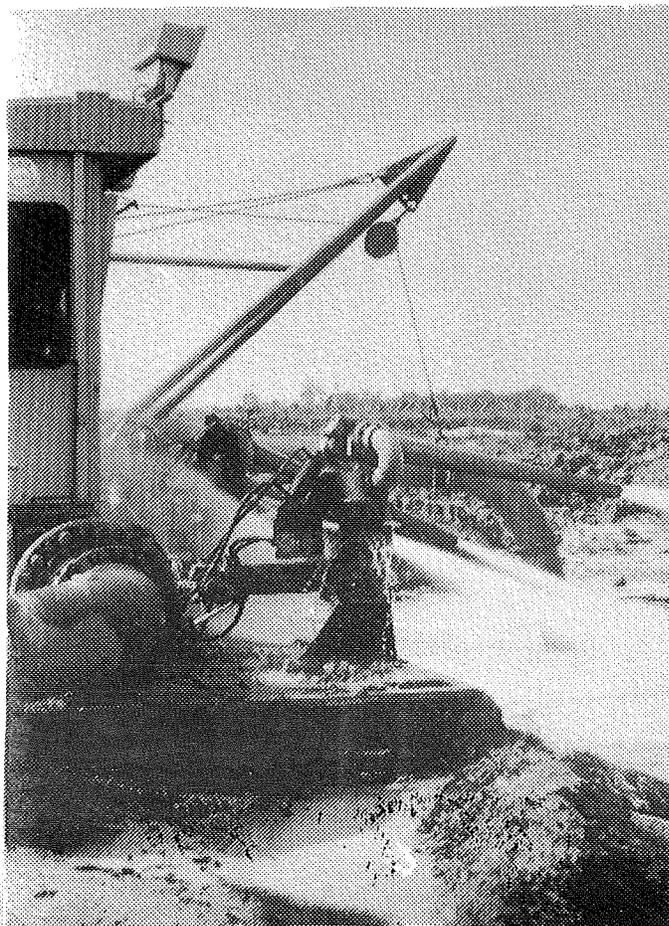
FIGURE 17. - Slurry pit or "well".

Water furnished to the monitors is usually water that has been used at the plant, clarified in settling ponds, and recirculated. The total amount of water used for ore slurrying varies from 5,000-12,000 GPM and depends on the physical characteristics of the ore (toughness) and the volume requirements (system capacity). The first ("stage") pump picks up the water from a reservoir and discharges it into the mine hydraulic line with the additional pumps acting as boosters for delivery to the "well". The water pressure at the gun tips, which ranges from 190-225 psi, is regulated by the number of pumps operated. The energy (gun pressure-volume) required to slurry or disaggregate the ore is a function of the clay content, moisture, and mineral composition of the ore.

Pumping systems used to transport the ore slurry from the "well" to the mill consist of a "pit pump" which picks up the slurry and discharges it into the pipeline, and booster pumps as necessary to maintain a minimum solids velocity of 12-15 feet per second in order to maintain suspension of the solids. Generally, the first lift pump is located within 1,500 feet of the pit pump, and additional lift pumps are spaced at approximate intervals throughout the system according to their size and the head developed. Figure 18 depicts a booster pump station. Note the dragline in the background.

FIGURE 18. - Pumping system.

Many pit pumps now in use are as large as 20 inches (opening) x 48.5 inches (diameter of chamber, dredge type pumps) with 45 to 48 inch diameter impellers, and are driven by 1,500 horsepower wound rotor motors with variable speed control effected through the use of grids and contactors. These pumps are controlled remotely and semi-automatically from the operator's car and can pump up to 1,200 tons per hour of ore.

Pipeline lengths presently in operation vary from several thousand feet to six or more miles. The length of the pipeline operated is limited by economics and not by exceeding the operating limits of the equipment used. Longer systems simply require more lift pumps. Pipe sizes are established by the minimum velocities needed to suspend the solids at the desired ore volume, matching pump capacity. Velocities range from 12 feet per second for fine-grained ore to 15 feet per second for coarse-grained ore. The percent solids in the slurry, particle size, and other factors have a distinct bearing on determining critical velocity (that is, minimum suspension velocity). Power and maintenance costs are the major cost factors in ore transportation.

Beneficiation

The majority of the basic technology in present use to recover and upgrade phosphate rock was developed prior to 1950. Increased market demand and more favorable economics of large capacity operations have provided incentive for technological advances in mining and processing equipment. Most newer mines are processing lower grade ore and high capacity equipment is critical to profitable operation. Future mines will encounter still lower grade ores with higher levels of refractory contaminants. Current research is aimed at developing technology to deal with these ores and improving existing processes.

Beneficiation techniques are dictated by the nature of the phosphate ore. The sedimentary deposits contain phosphate pellets, ranging in size from 3/4 inch (19 mm) to 200 mesh (74 microns), in a matrix of quartz sand and clay minerals. The quartz sand, mostly finer than 35 mesh (435 microns), ranges as coarse as 16 mesh (1,000 microns), while the clay minerals are finer than 400 mesh (37 microns).

The size of beneficiation equipment is determined by the desired or most practical production rate and the constituency of the ore in terms of recoverable product from the various mesh increments above. The concentration of recoverable product in the mined ore is termed the "matrix ratio" or matrix "X", and is usually expressed in yards of ore per short dry ton of recoverable product. An ore that yields one ton of recoverable product per five yards of ore beneficiated has a matrix "X" of 5; the lower the matrix "X", the more concentrated the ore. Concentrations of ore in Florida range from 1.0 to ∞ in matrix "X"; recognition of a deposit for this study was limited

to phosphorites of less than 10 matrix "X" (see table 15). Below are listed ore concentrations for "typical" deposits in the identified districts:

District	Matrix "X"
Central Florida	2.5-4.0
Northern Florida	3.5-6.0
"South Florida"	3.0-6.0
Hardrock	4.0-8.9 (pebble only)
"East Coast"	3.5-5.0

As discussed in the Characterization of Resources section, the matrix "X" in some deposits is determined by the optimum balance between production rate, equipment sizing, and ore body size. Inclusion or exclusion of less concentrated strata will affect the average matrix "X".

The concepts of phosphate rock beneficiation have evolved by trial and error during the last 70 years. Processing steps, common to all Florida land-pebble mines, include matrix washing, feed preparation, and flotation. Early process facilities recovered only pebble phosphate. Pebble, or phosphate coarser than 1 mm, was recovered from the ore by washing out and rejecting the clay minerals and sand by sizing at 1 mm. The development of froth flotation made recovery of phosphate from the washer debris (that is, -1 mm) possible for fractions greater than 150-200 mesh (74 microns). It was never applied to hardrock deposits.

Washer Plant

The primary function of a washing plant is to remove pebble (+1 mm) material from the matrix, and disaggregate the ore in water so that clay minerals can be separated from quartz sand and phosphate fines by sizing. Washer plants utilize sizing and attritioning devices in series for liberation and separation of materials.

The phosphate ore is received from the mine in slurry form. The slurry is scalped at nominally 3/4 inch by trommel screens, and the oversize is disintegrated by hammermills in closed circuit with the trommels. Flume or flat screens remove slimes and flotation feed from the pebble circuit. Pebble cleaning is achieved by alternately sizing with vibrating screens and attritioning with log washers. The final product ranges from 5-25% of the matrix weight at grades of about 60-70% BPL. Pebble grade in central Florida is directly related to the amount of contained or tramp fines (-16 mesh), since fines are lower grade and reduce the product grade. In other areas, carbonate content becomes the more important factor, with limestone or dolomite chips a common contaminant.
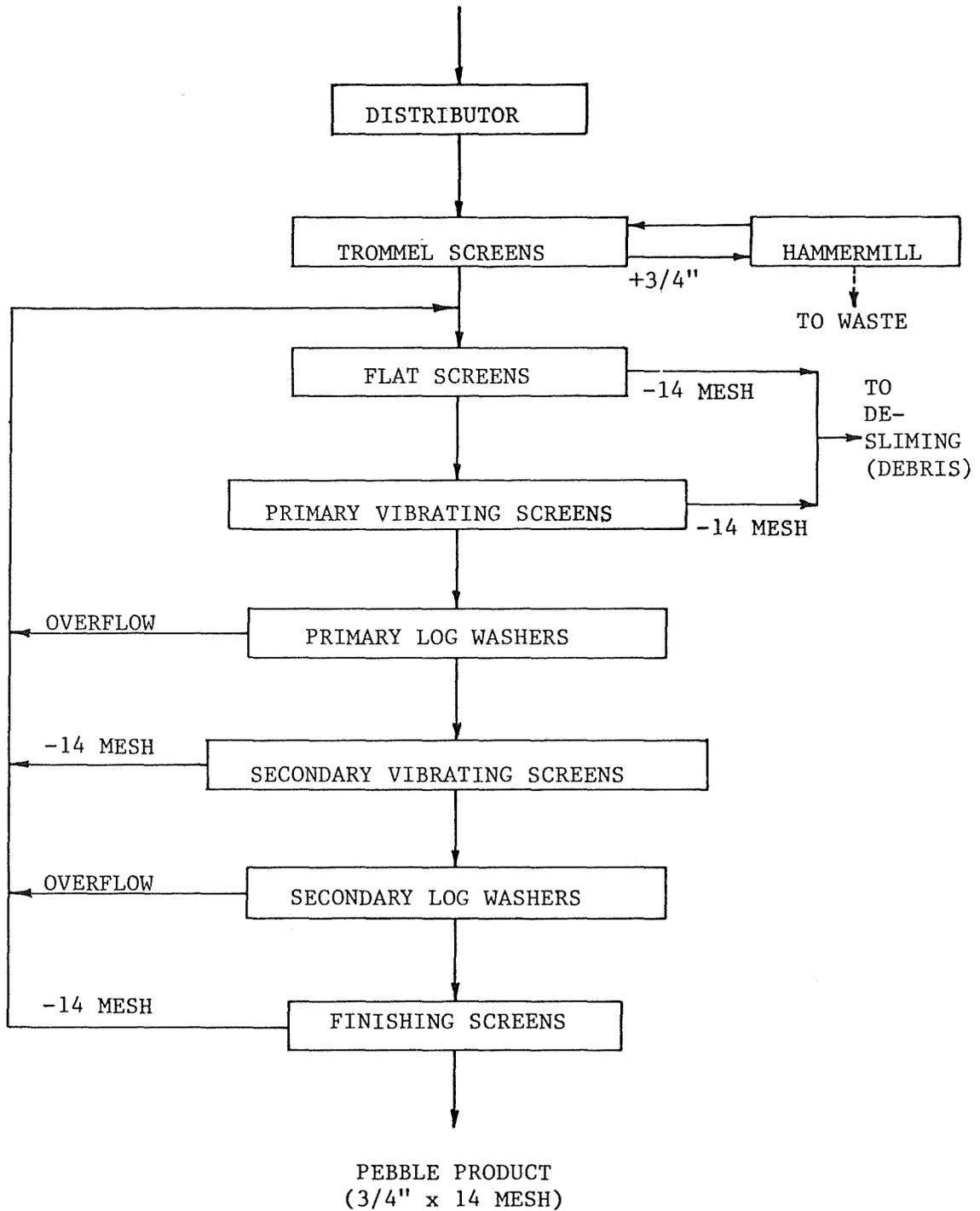
FIGURE 19.-Flowsheet for washing phosphate ore.

A conventional washer flowsheet is given in figure 19 and a photo of an operating facility is shown in figure 20. The pebble product is stored in pebble bins for dewatering and quality control analysis prior to shipping or placement on wet rock storage piles.
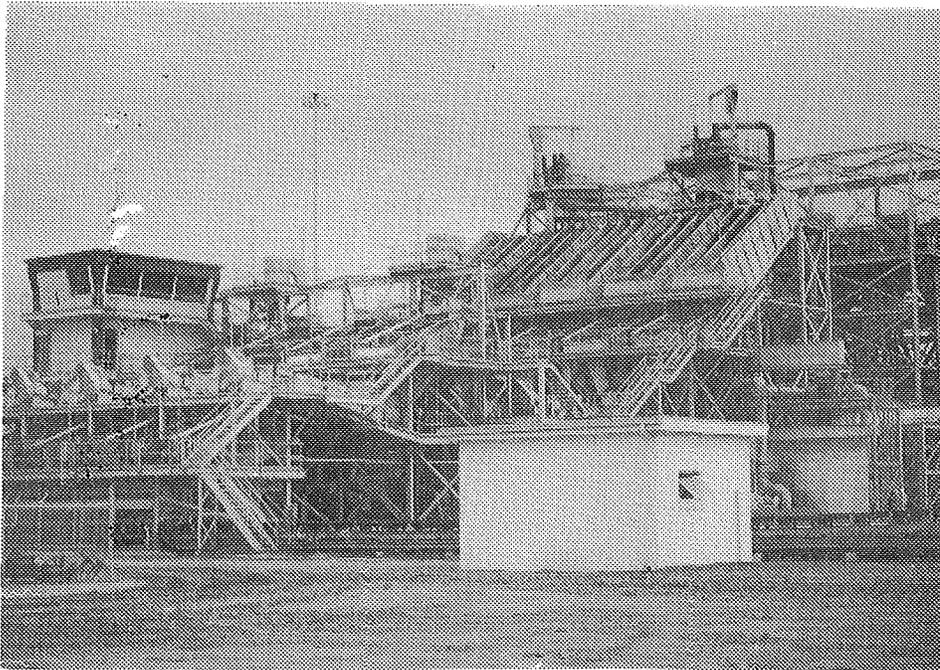
FIGURE 20. - Washer facility.

Feed Preparation

Preparation of the washer debris (material passing 1 millimeter) is necessary for subsequent flotation. Clays must be separated from the flotation feed prior to the addition of flotation reagents since clays adsorb reagents, preventing flotation. Desliming is accomplished by sizing the feed at nominally 150 mesh in two or more stages of hydrocyclones. The hydrocyclone overflow product (-150 mesh) is discharged to clay disposal areas as a waste by-product. Typically 2-3% of the near size 150 mesh feed is lost to clay waste due to cycloning inefficiencies.

Feed preparation circuits are designed to provide storage and surge capacity so that feed rates to sizing and flotation can be controlled independent of stripping rates and mining and pumping ore to the washer. Static screens and/or hydraulic sizers and vibrating screens are used to separate the feed into size fractions for reagentizing and flotation. Three nominal size fractions are recognized: intermediate pebble (+20 mesh), coarse feed (20 by 35 mesh), and fine feed (-35 mesh). The deslimed feed may be sized at 20 mesh, 35 mesh, both, or left unsized depending upon grade and distribution of BPL values.

The +20 mesh feed, which is too coarse for effective recovery by conventional double flotation, requires blending with other products, or upgrading. The upgrading techniques include agglomeration or skin flotation processes and straight amine flotation. The 20 by 150 mesh feed can be upgraded by double flotation, and maximum recovery is attained by reagentizing and floating coarse feed (+35 mesh) and fine feed (-35 mesh) separately.
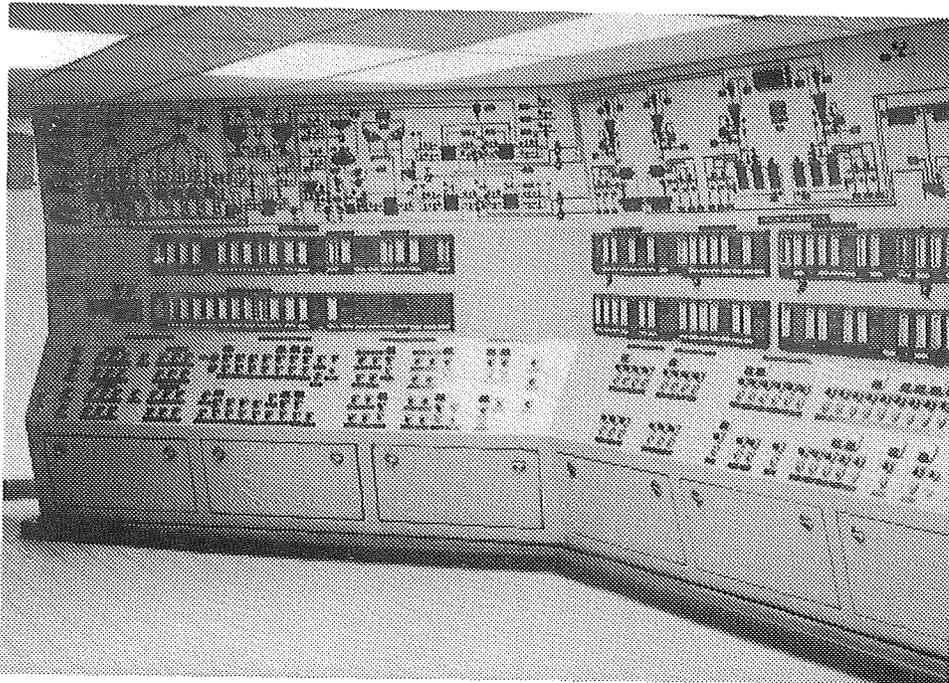
FIGURE 21. - Control panel, modern flotation plant.

Flotation

Flotation plant control rooms as shown in figure 21 are essential for efficient operation. Both froth flotation and skin flotation techniques are used to recover concentrated phosphate rock. Anionic reagents are used to condition the feed for the rougher flotation step. Efficient attachment of anionic collector to the phosphate grains requires high density (+65% solids by weight) conditioning. Fine feed can be conditioned in vertical agitated tanks; however, coarse feed requires rotary drum conditioners. Rougher froth flotation is conducted in conventional flotation machines ranging up to 500 cubic feet in size (figure 22). The skin flotation processes utilize spirals, Lang Launders, or belts. Concentrates from rougher froth flotation, belt flotation, and Lang Launders usually require further cleaning by flotation to remove additional silica in order to make acceptable product grade. Recoveries obtained by anionic flotation range from 90-95% for properly sized feed.
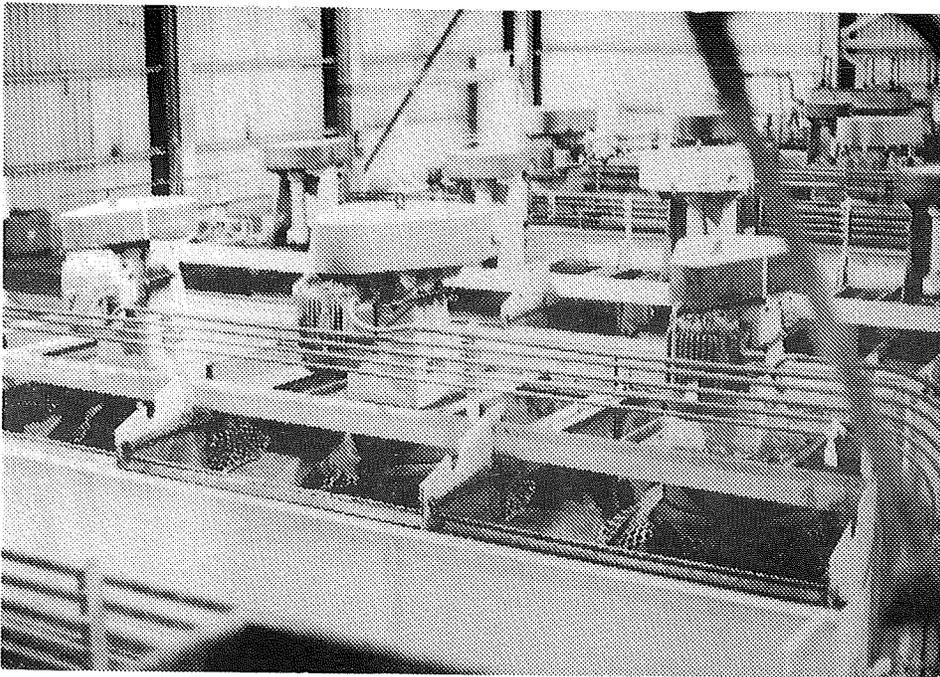
FIGURE 22. — Five hundred cubic foot flotation cells.

A flowsheet illustrating a process for intermediate pebble bene-
ficiation is illustrated on figure 23.

Prior to final cleaning, rougher concentrates are de-oiled by sulfuric
acid scrubbing and rinsing to remove anionic reagents. Scrubbing is
conducted in vertical agitated tanks and rinsing is achieved by hydro-
cyclones and wash boxes.

The de-oiled rougher concentrates are pulped with high quality water,
conditioned with cationic reagents, and transferred to flotation cells to
remove remaining free quartz sand. Well water is normally used for cleaner
flotation to avoid suspended solids and other contaminants that cause poor
or irregular response, with associated excessive consumption of cationic
collector and/or grade problems. Cleaner flotation, conducted in
conventional flotation machines, yields final or cleaner concentrates
containing 2-5% acid insolubles (primarily SiO_2). Cationic flotation
recoveries range from 90-95%. A typical flowsheet for feed preparation
and flotation is given on figure 24.
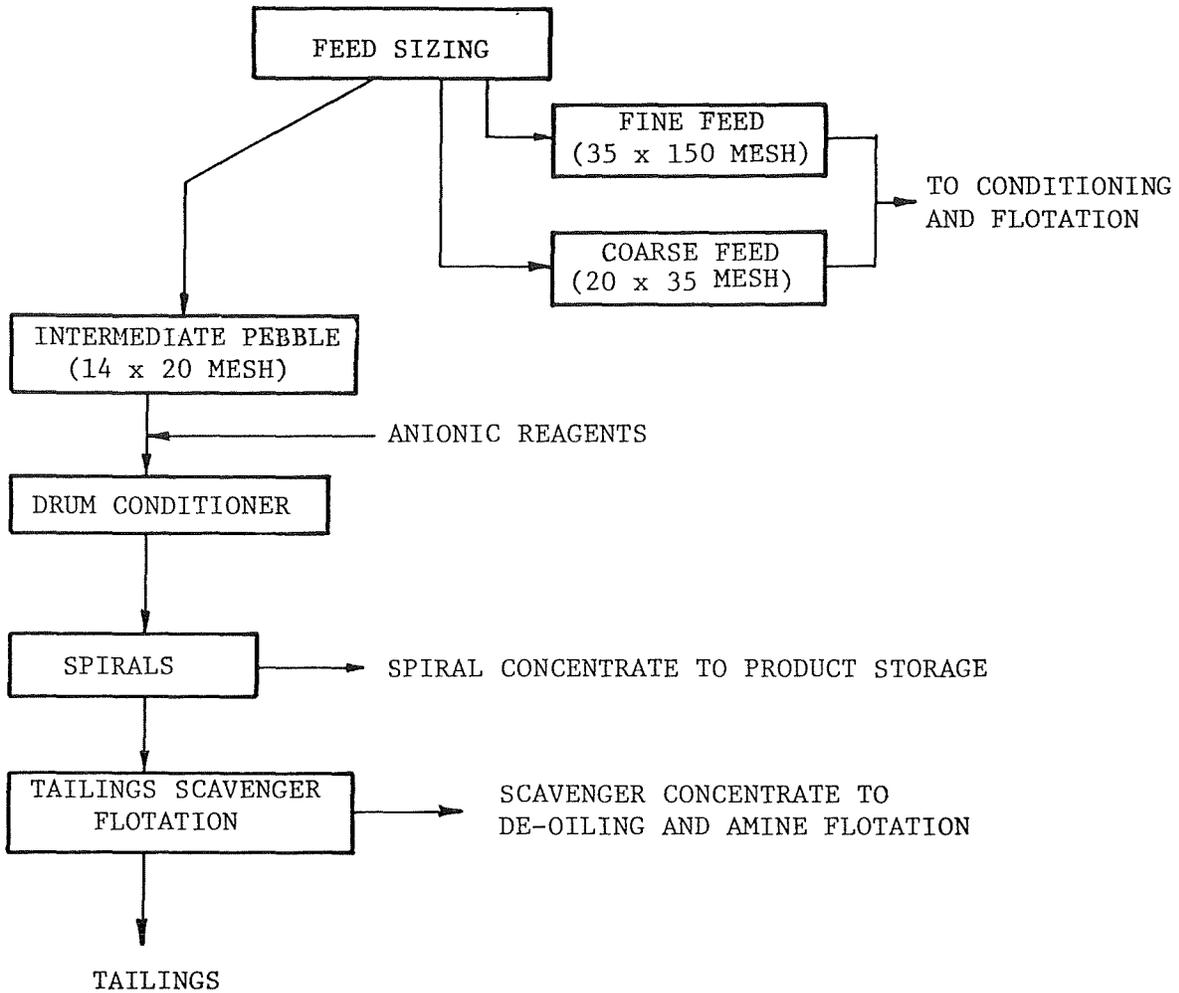
FIGURE 23. - Typical spiral flowsheet for intermediate pebble beneficiation.
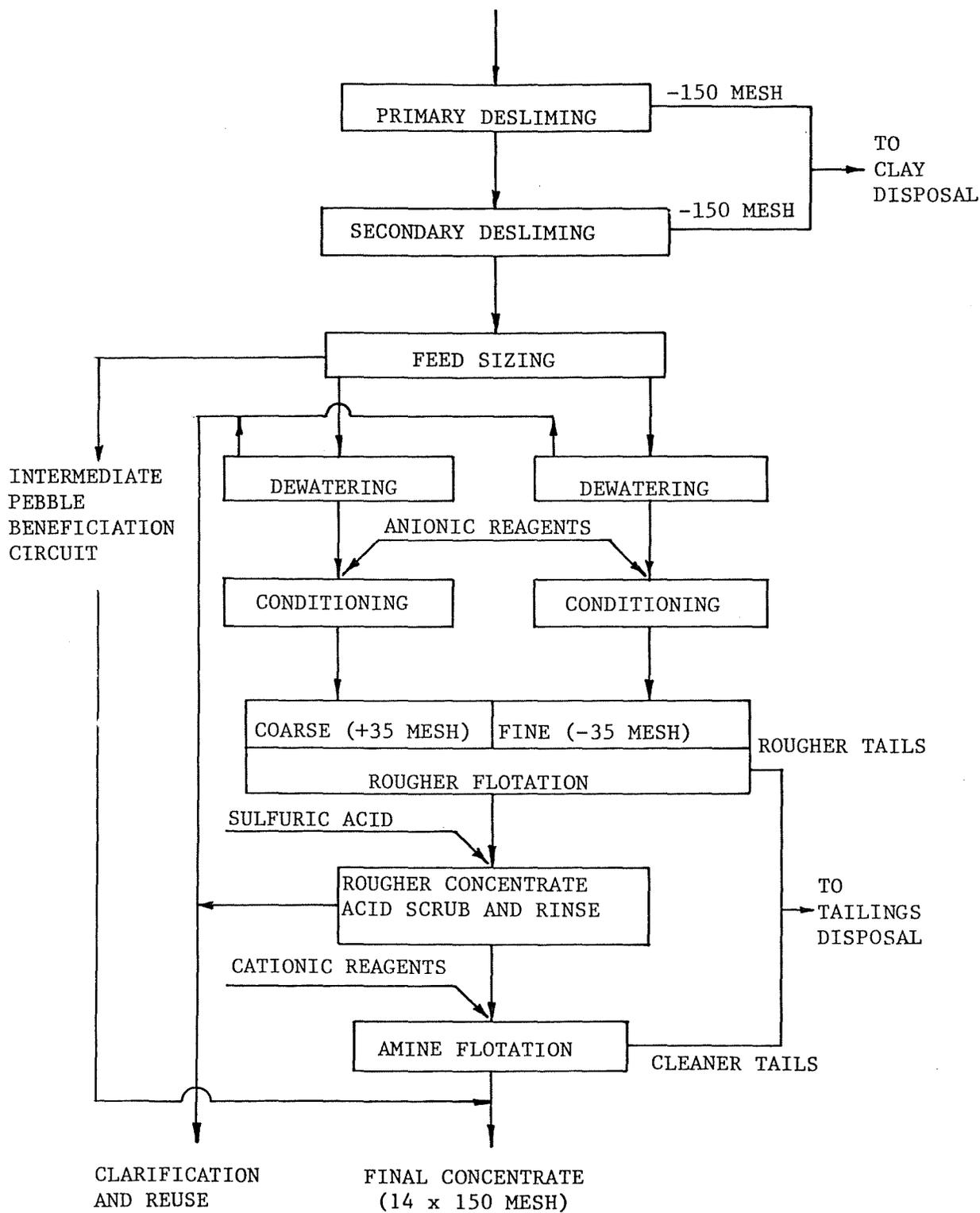
FIGURE 24. — Feed preparation-flotation flowsheet.

The anionic collectors used for rougher flotation are by-products from pulp and paper processing. These reagents are soap skimmings and crude tall oil, including tall oil distillation products such as tall oil heads and tall oil fatty acids. Fuel oil is used as an extender to reduce collector consumption and also to provide froth control. Anionic conditioning is conducted at a pH ranging from 8.5 up to 10, as maintained by NaOH and NH_4OH.

Sulfuric acid is used for scrubbing rougher concentrates at pH 4 or less. The cationic collectors used for cleaner flotation include tallow amines and condensate amines. Kerosene is used as an extender and pH control in the range of 6.5-7.5 is achieved with either NaOH or NH_4OH.

A typical overall (two-stage) flotation performance would reject 99% of the free quartz sand and recover 80% of the phosphate grains from the flotation plant feed. Flotation concentrate is usually stored in bins for dewatering and quality control analysis prior to shipping and/or placement on wet rock storage piles. Phosphate rock extracted as flotation concentrates varies from 10-25% of the ore weight.

FIGURE 25. - Product bins.

Product Storage, Drying and Shipping

Some producers ship wet rock directly from product bins (figure 25);
however, most operators use wet rock storage piles to segregate product by
grade and quality. Product recovered from storage can be blended to meet
shipping specifications. Mine planning must include considerations of
operation to maintain a resonable mining sequence through ore of different
richness or quality, while sustaining a uniform rate of product shipment
tonnage and quality. Storage pile capacity ranges from about 500,000-1,500,000
or more short tons, depending on ore variability and production schedules.
Figure 26 shows the conveyor carrying wet rock from the washer to the storage
pile.
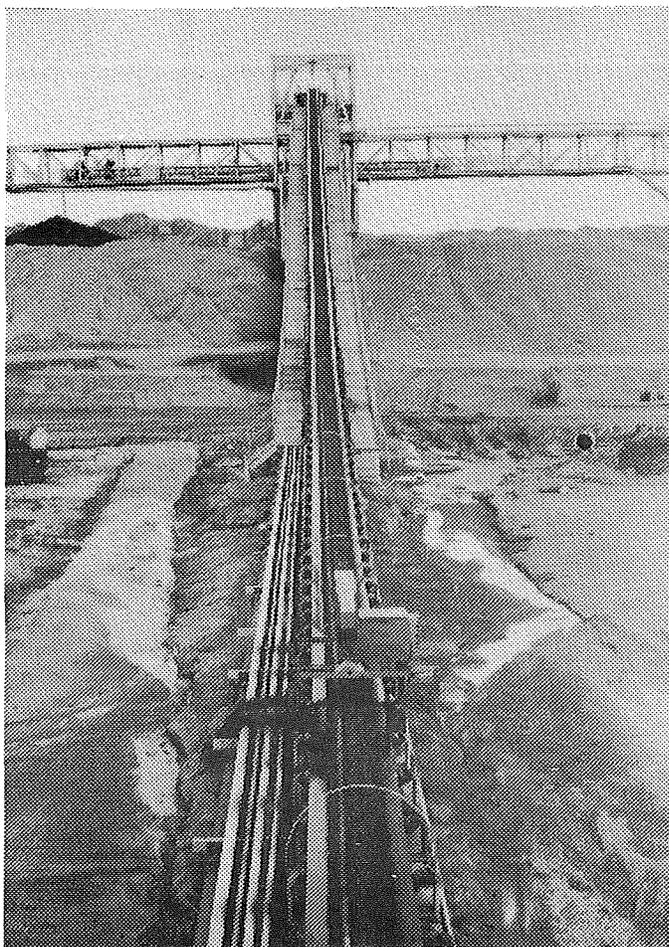
FIGURE 26. - Wet rock storage.

Less product is being dried than previously because of the conversion
from dry to wet rock grinding in some domestic phosphoric acid plants. Exist-
ing facilities consist of either rotary or fluid bed dryers, with the more
fuel efficient fluid bed types being installed in all new plants. The fluid
bed dryers range up to 500 short tons per hour capacity.

Product Losses

An evaluation of phosphate beneficiation must consider product losses rather than BPL losses, because not all ore BPL (P_2O_5) can be converted to product. The clay fraction (slimes) may contain 15-40% of the BPL values in the ore, but these are not currently considered feasible for recovery. Phosphate minerals in the slimes are often high in iron and aluminum which complicate chemical extraction, and flotation techniques are limited by particle size and excessive reagent consumption.

Losses of pebble and concentrate result due to inefficiencies in screening (washer) and desliming (feed preparation). Pebble losses to the flotation feed typically range from 2-7%. Concentrate losses of 1-3% result because of feed losses to the clay waste.

Concentrate losses result primarily in the flotation process, usually due to particle size considerations in conditioning and flotation. Beneficiation flowsheets are based on the grade and distribution of BPL in each feed fraction.

Beneficiation Improvements

Larger volume flotation cells which reduce the number of circuits and floor space are being installed in new plants thereby simplifying plant design. Screening devices which permit finer size separations without cloth blinding are being given serious consideration for intermediate pebble sizing applications.

Future mines will process low grade ore containing little acceptable grade pebble. The lack of pebble product will press producers to maximize recovery of flotation concentrate and in many cases beneficiate low grade pebble. The South Florida ore bodies are known to require considerable development work to optimize flotation recovery and product grade. The magnesium content of some Florida phosphate ores is sufficiently high to limit the tonnage of presently saleable product, because the standard double flotation process does not efficiently reject calcium or magnesium carbonates. Flotation processes for rejecting liberated dolomitic particles are being studied by several investigators.

Waste Disposal

Florida currently produces phosphate rock from about twenty beneficiation plants. Annual production averages 2,200,000 short tons per operating plant, and ranges in capacity from about 100,000-4,800,000 short tons of product per year.

A typical materials balance for a 2,200,000 short ton per year operation in central Florida is given in table 2:

TABLE 2. – Distribution of ore constituents by % BPL (typical)

	Short tons per year (dry) (thousands)	% BPL grade	% Ore (dry wt)
Phosphate pebble..........	1,056	68	12
Flotation concentrate.....	1,144	72	13
Clay waste (slimes).......	2,200	20	25
Flotation tailings........	4,400	5	50
Matrix composite.....	8,800	25	100

The above balance is also illustrated in figure 27. The illustration shows that two tons of tailings and one ton of clay waste are generated for every ton of product in this typical example.
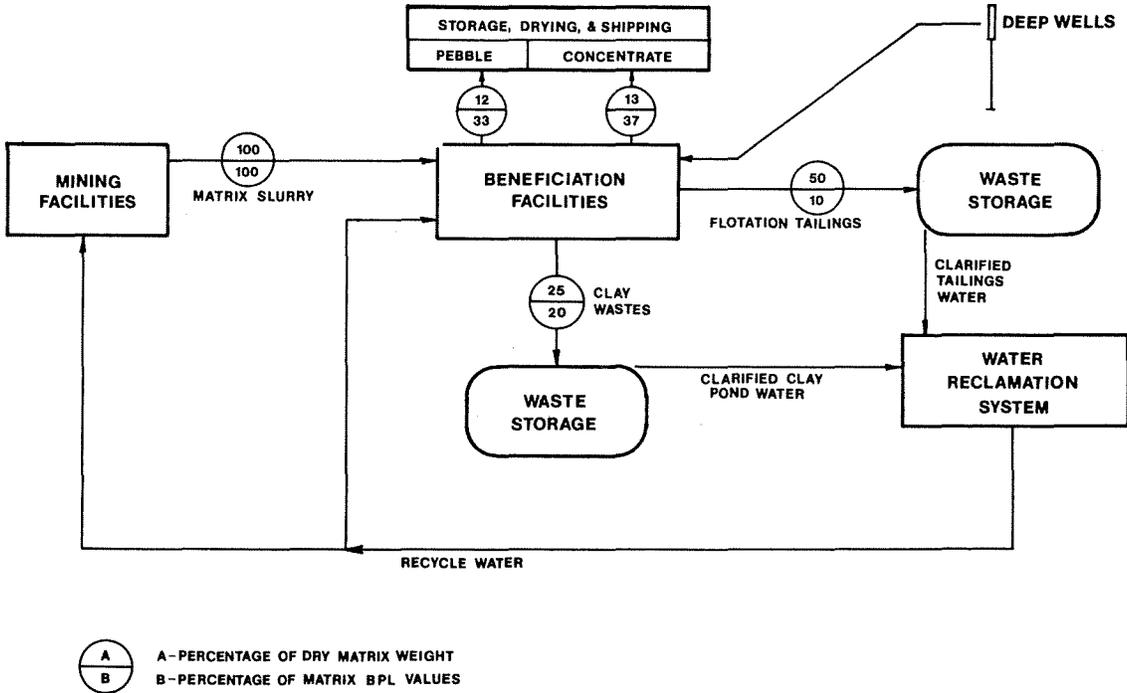
FIGURE 27.– Typical phosphate mining and beneficiation material flow.

    Clay minerals in the slimes such as montmorillonite and attapulgite
are extremely difficult to dewater. Current technology utilizes large
impounded settling areas such as shown in figure 28 to dewater the clay
slurry from an initial 3% to 18% solids by weight after a considerable
period of time. Extensive studies of improved dewatering techniques have
outlined three potential methods: sand spraying, flocculation-mix, and
dredge-mix. The primary objective of the studies is to eliminate the need
for above-ground impoundments, but additional water recovery is also of
great importance.
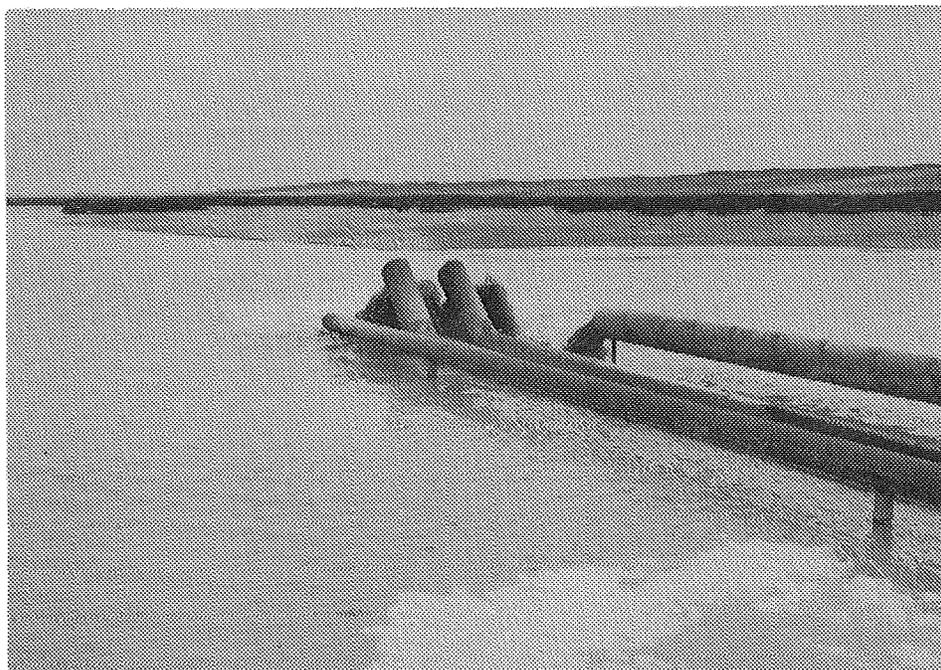
       FIGURE 28. - Waste clay discharge and retention pond.

    In the sand spraying method, sand tailings are sprayed over naturally
settled (12-15% solids) clays and the resultant compaction and channeling
releases water. The mixing operation takes place in mined-out cuts;
therefore, detailed planning and scheduling of events is required. Several
stages of clay input, settling, and sand spraying may occur before dewater-
ing and backfilling is complete.

    Chemical flocculants and thickeners are utilized in the flocculation-
mix technique to induce initial quick dewatering of the clay slurry to
about 12% solids. The thickened clay slurry may be used to repulp
dewatered flotation tailings, and the mixture pumped to reclamation site
areas where additional dewatering occurs, forming a reasonably stable fill.

In the dredge-mix method, thickened clay dredged from conventional settling ponds is mixed with dewatered sand tailings and pumped to mined-out cuts. This technique is independent of operating desliming facilities.

Flotation tailings alone are readily dewatered when placed in mined-out areas and, of course, make a stable land fill for reclamation. The three alternate clay dewatering processes may all involve mixing the tailings with clay, but flocculation disposal does not necessarily require tailings to be used for waste disposal.

The need for expensive dams to impound wastes would be reduced if clay waste could be solidified sufficiently by one of the above methods or other methods for use as backfill. Typical ore constituency and mine void production indicate that the clay slurry must be dewatered to approximately 30+% solids for the backfill not to exceed the previous ground elevation in typical Central Florida mines.

Current waste disposal techniques recover approximately 90% of the process water for reuse. Typical water losses expressed as gallons per ton based on conventional waste disposal techniques in the average 2,200,000 tons per year operation previously described are tabulated in table 3.

TABLE 3. - Water lost from typical mine water system

(Basis: table 2)

	Gallons/ton	Disposition
Per ton of product...	60	Shipped or evaporated from dryer.
Per ton of tailings..	60	Interstitial water in sand.
Per ton of clay......	970	Water retained by clay slurry.

The amount of water lost from the mine water regime is a function of the richness of the ore and most significantly a function of the product-to-clay-content ratio. Each ore body has a unique water balance and losses cannot be generalized. Alternative or additional innovative waste disposal techniques promise to reduce water losses because of improved clay dewatering.

Water Requirements

Mining of phosphate in Florida has traditionally used water in both the transportation and beneficiation of the ore. Water is used as the medium for conveying ore to the mill, attritioning the ore, and separating clay, sand, and pebble size fractions at the washer. In the size classification and flotation steps that follow, water is again the medium, and finally is used for pumping waste clay and sand tailings from the mill. Recovery and recirculation of water occurs in the ore transportation-beneficiation-waste disposal-water clarification process, and is essential since the gallonages required are large. Mines commonly recirculate 90% of the water used, with the remainder lost from the system. Water losses within the system can occur due to entrainment in the sand and clay waste, evaporation, seepage into the surficial aquifer, rock shipment, or drying of the product.

Water is provided to the recirculating water system from moisture included in the matrix, by rainfall into the process pools and ditches, by pumping water from deep wells and occasionally by the use of surface water from local streams. The volume of water required for make-up is usually a direct function of the losses incurred to the system, although it is possible for water quality requirements in the flotation process to establish the demand. The water balance and demand can vary significantly due to production rate, ore composition, management of the water system, and other variables.

The water balance will shift seasonally in Florida in response to dramatic changes in rainfall, evaporation, and surface runoff accumulation into the system. Seasonal changes may shift the system balance from water needed for the process only to water make-up for the total system losses. Each mining system must be examined for its specific requirements according to ore characteristics, system design, losses, and flotation process requirements.

A typical mine water system (figure 29) is composed of the mine area, water pools, ditches, piping, waste disposal areas, and portions of the mill which contain and utilize water. The proper design of the total water system is of upmost importance not only from the standpoint of cost and process demand, but also because of the pronounced attention given to conservation of the state's water resources.

The water balance is the tabulation of the sources and disposition of water for the total system. Sources must equal losses for system balance. For example, should sources exceed losses, the water system will fill and discharge may be necessary from the pools and ditches. Conversely, should the disposition of water exceed the make-up of water to the system, the pools and ditches of the system would eventually go dry. Because of distinct seasonal rainfall changes, the system's design considers the optimum storage requirements balancing demand and discharge.

Matrix

Wet Solids In

Deep Wells

Plant Supply

Rainfall

Stream

Reservoir
Surface Water

Wet
Product

Sand Disposal

Clay
Disposal Area

Water
Retained
in Wet
Solids

Recovered
Water
Recycled

Evaporation

Mine Water System
Pool & Ditches

Discharge

Level Control

Seepage
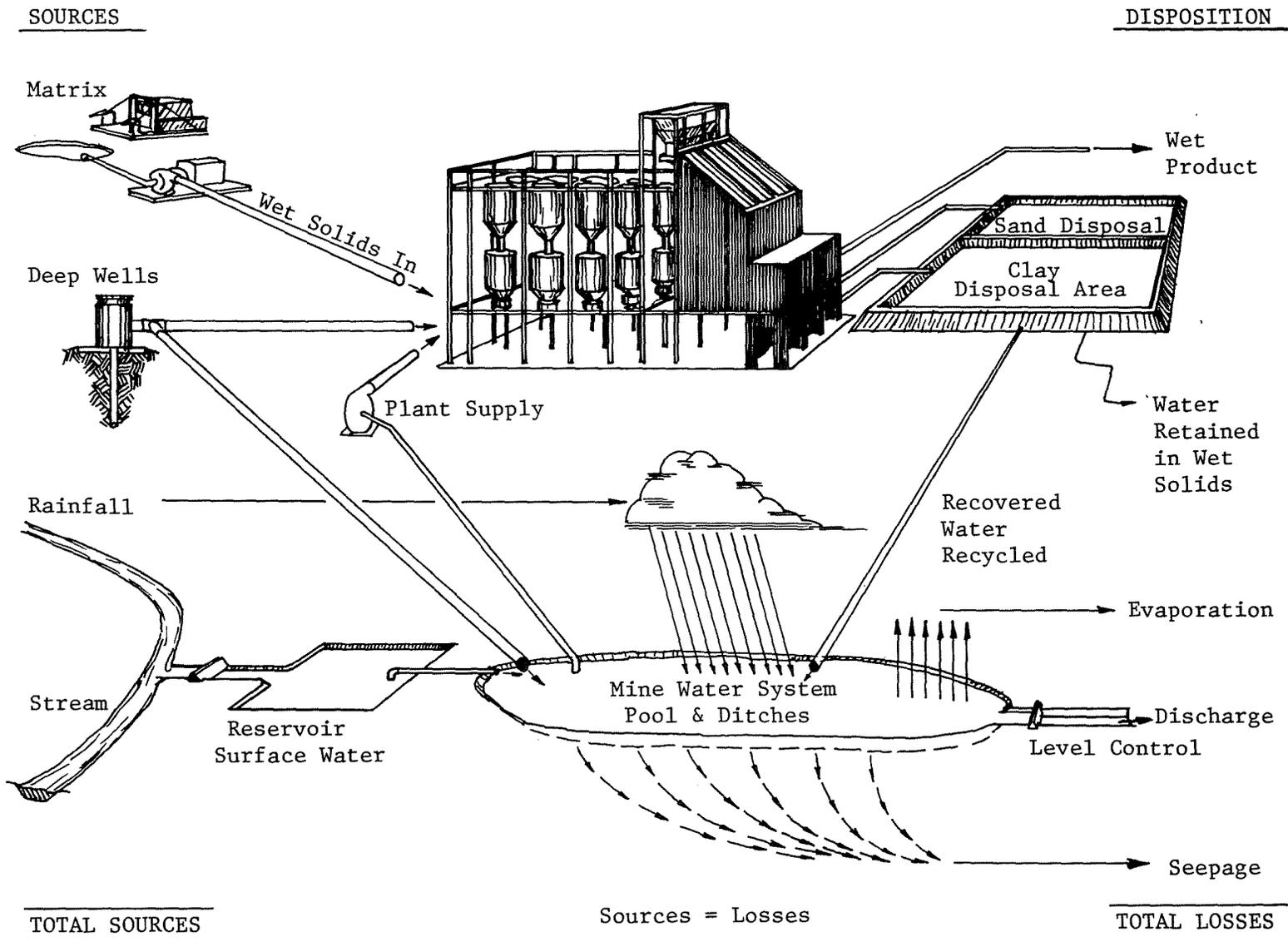
Sources = Losses

FIGURE 29.—Mine water system.

The advantages of using the water balance in determining system requirements is that it is straightforward and correctly represents water needs without the complex study of internal flows such as recycles within the plant. The concept of the water balance has been generally accepted and is used to define water needs for permitting purposes. In figure 29, water is supplied directly to the mill and also recycled from the pool. Recovered water is recycled from the waste disposal ponds to the water system pool at the mill. This recycle rate, in many cases, represents 90-92% of the water requirements which the plant and waste disposal system need for material and waste transportation.

Water Sources

Phosphate ore contains moisture and is a source of water to the recirculating system. The water in the ore must be considered in the water balance since it is an integral part of the system water although it is not derived from the available regional supply.

- Wells from up to 1,600 feet deep are commonly used as a source of make-up water. As shown in the example, some water is introduced to the mill while other water from deep wells may go directly into the recirculating water system. Deep well water is often required in the mill to operate the water quality-sensitive amine flotation section. When poor quality or turbid water is used, the amine flotation efficiency falls off rapidly. Deep well water may be added to the mine water system to make up system losses.

- Rainfall is also a water source. Wide seasonal variations and unreliability make its contribution difficult to gauge. Evaporation is a loss to the system which is also seasonal in nature. Rainfall closely matches evaporation on a long term average basis. During the last decade, however, evaporation has substantially exceeded annual rainfall. Some water from rainfall runoff of the land areas surrounding the mine water system pools and ditches can be accumulated in rainy seasons, offsetting net evaporation losses. The system would have to be designed to capture rainfall on the surrounding land to offset these net evaporation losses, and have the capacity to hold this excess until needed.

- Some minor amount of water may be derived from the surface aquifer for pump seal water or other limited uses.

- Surface water can also be a source to the system if it is readily available and is permitted by regulatory authorities. Surface water resources withdrawn from streams into reservoirs are shown in figure 29. Limitations on stream withdrawal are based on maintenance of minimum flow rates and other downstream uses.

System Losses

Water balance calculations are made based on detailed prospecting data for the specific ore body. The key data utilized for the balance are: 1) product yield per ton of ore mined, 2) tails generated, 3) clay produced and 4) clay settling (water release) characteristics. Careful attention to the variations in annual mining conditions throughout the life of the operation is required. See figure 31 for comparison of examples of various types of ore.

Losses are defined as water that is rendered unavailable to the system. The major losses are discussed below:

- Product Moisture. Water which is retained interstitially in the wet phosphate rock is lost from the system when the rock is shipped from the site or dried.

- Tailings and Waste Pebble. These are similar to the product losses. Tailings and waste pebble are placed in waste disposal sites at 30-40% solids. They readily consolidate to approximately 80% solids and the water is retrieved. The 20% interstitial moisture retained is displaced from the system.

- Evapotranspiration. Transpiration is not a significant part of the losses to the water system. Evaporation is a direct function of seasonal climatic conditions. In Florida it is recognized that evaporation has exceeded rainfall on an annual basis in the last 7-10 years, and commonly 8-9 months out of twelve. This evaporation loss is offset to the extent rainfall or seepage is collected into the mine system.

- Clay Entrainment. Waste clays extracted from the phosphate ore create most of the water system losses. Clay is separated and deposited as waste in retention areas at approximately 94-97% water content. Within 12-30 months the slow settling of clay solids reduces moisture content to approximately 80-85%, substantially above the natural state within the ore, where the clay contains 40-60% water. This retention of water is depicted in figure 30. Absorption may be reduced by accomplishing greater solidification of clay solids. Presently, methodology such as the flocculation or sand-clay mixing procedures are being tested and receiving considerable attention in the field as a means of increasing or accelerating clay solidification. The primary purpose in these studies has been to minimize clay waste disposal ponds and enhance land reclamation. It has been established in limited test programs that high solidification of clays can be achieved (up to 25-30%); however, the amount of water released which can be recovered for the purposes of recycle has not been defined.

NOTE: VOLUMES ARE IN CUBIC YARDS

☐ WATER

▨ ORIGINAL ORE MOISTURE

▤ CLAY

▨ SLURRY

15.5

PROCESS
WATER
ADDED

RECYCLED
WATER

3.8

WATER
RETAINED
BY CLAY

1.46

1.46

0.36

0.36

0

0

INITIAL
SLURRY

SETTLED
SLURRY
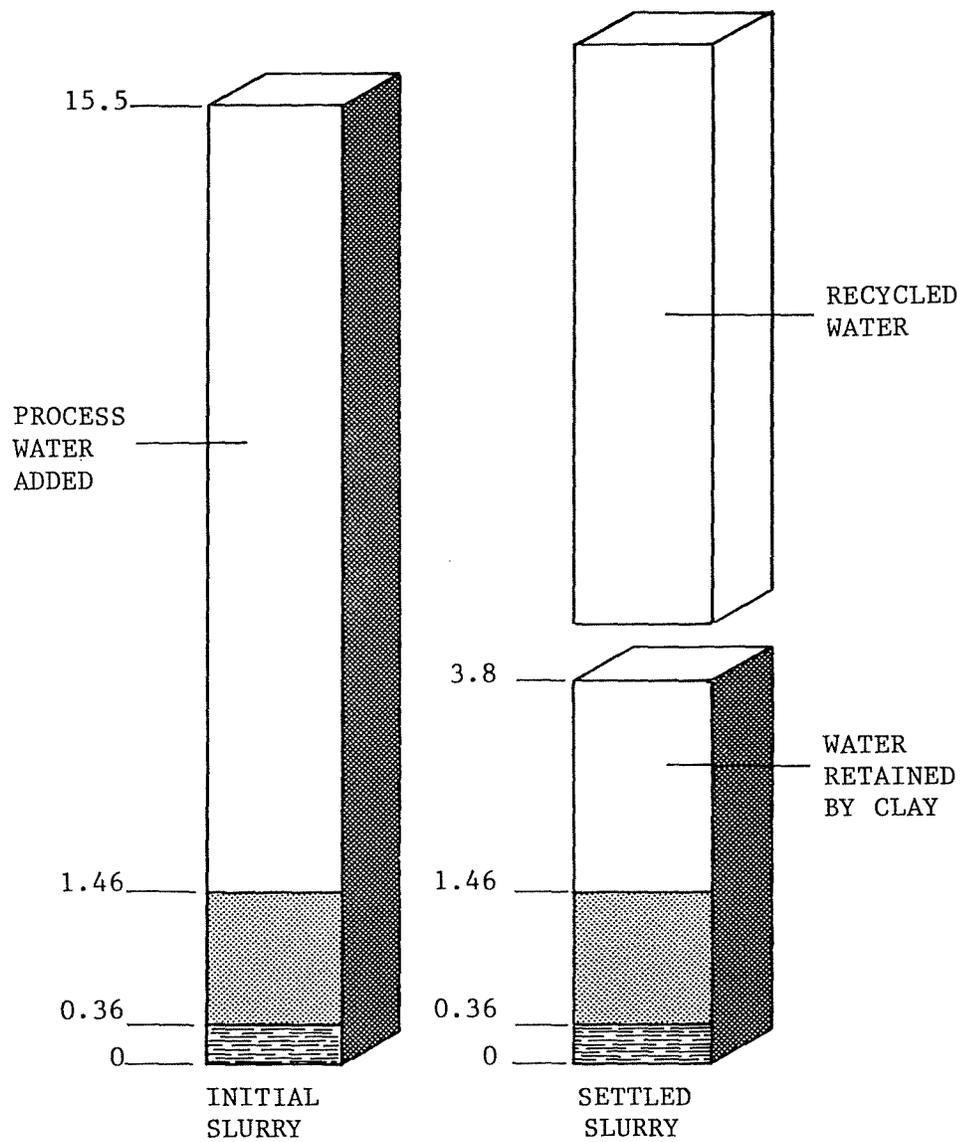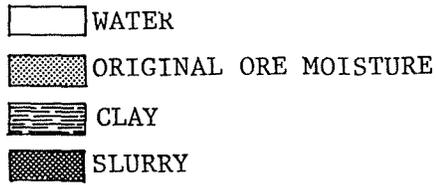
EXAMPLE OF SMALL B ORE

FIGURE 30. – Absorption of water by clay basis: one ton of product produced.

- Seepage. The above grade dams and dikes constructed to contain water or clay wastes incur losses of water through seepage through the impounding embankment.

- Discharge. Water is released due to high pool water levels or exceeding the system's volumetric capacity.

Adequate design of the total water system is necessary to allow proper management. Discharge of water from the system is to be minimized from the standpoint of conservation and cost (energy), although overdesign for complete containment could be equally wasteful. With proper system design and management, discharges will occur only in cases of extreme rainfall events.

Energy Requirements

Electrical power, fuel oil, and gas provide the energy required to mine and upgrade phosphate rock to a saleable product. Electric motors are utilized to power the walking draglines, slurry pumps, water pumps, and other process equipment. Fuel oil is consumed by bulldozers, miscellaneous portable mine equipment, and for product drying. Existing dryers are generally fired as available by gas, with oil as standby. Future dryers will rely on fuel oil and possibly pulverized coal.

Typical energy requirements per ton of ore are approximated below, based on design data for proposed mines:

TABLE 4. - Energy requirements per ton of ore

	Installed horsepower[1]	Gallons fuel
Mining facilities.....................	12	[2] 0.017
Beneficiation facilities..............	10	0.003
Waste disposal facilities.............	4	0.010
Total	26	0.030

[1] Motor Horsepower ÷ Tons Ore Per Hour

[2] Does not include dryer fuel.

Actual power consumption (kilowatt hours) is a function of materials handling; it therefore depends on stripping ratio, ore concentration, and distance. A brief description by area is given below.
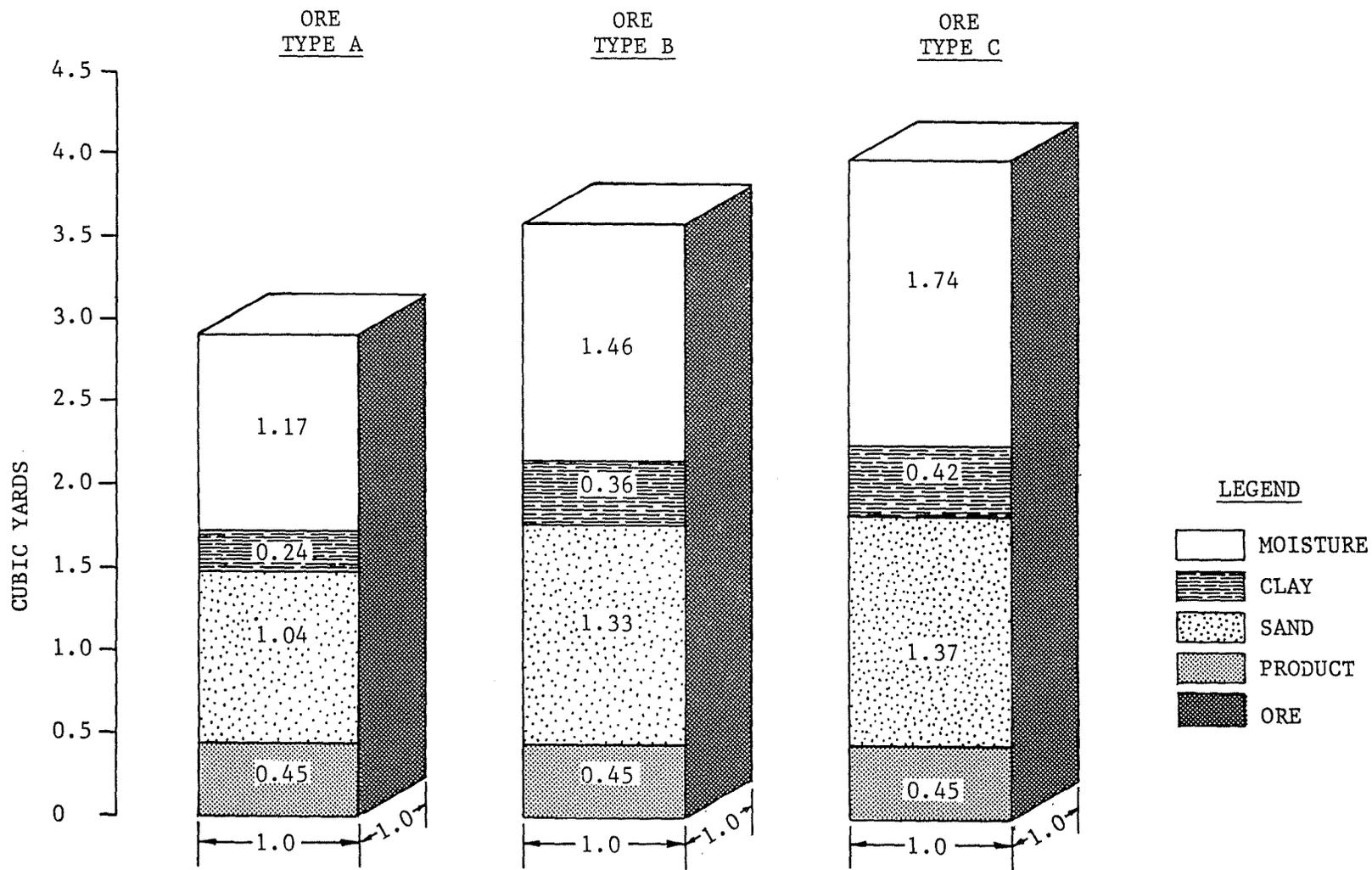
NOTE: 0.45 CUBIC YARDS OF PRODUCT ≅ 1 TON OF PRODUCT

FIGURE 31.— Comparison of ore constituent.

Mine

The energy consuming functions in the mine consist of excavation, ore transportation and support equipment operation. Excavation and ore transportation equipment is generally electric powered, while mobile equipment such as pipe layers, road graders, etc. use diesel fuel.

Conventionally, draglines are used to remove the overburden and excavate the phosphate ore. The large walking draglines vary in size (14 cubic yard to 75 cubic yard bucket capacity) and use large electric motors. Total horsepower of large machines ranges from less than 3,600 up to 7,000.

Draglines are widely accepted in the industry because of the unit power cost efficiencies. In order to determine the unit excavation power consumption for phosphate ore, the ratio of overburden to phosphate ore must be known. Using 1.25-1.75 kW-hr per ton as an average excavation power use and assuming a 1:1 overburden-ore volume ratio, the total excavation power required per ton of ore is 2.50-3.50 kW-hr. If the overburden-ore ratio is increased, the unit consumption is increased directly.

Dredges utilized as excavators have unit power usage and costs generally considerably higher than draglines. This is a direct result of having to transport the overburden material hydraulically a considerable distance beyond the immediate excavation site. Again assuming a 1:1 overburden-ore ratio, the consumption of power in excavation is 3.00-4.00 kW-hr. This cost applies only to the overburden since the excavation of the ore itself is actually an ore pumping function. A small portion of the unit power usage (18%) applies to mechanical horsepower used in cutting the overburden material into a slurry form. In the overall mining area approximately 30% of the total energy requirements is used in stripping overburden and excavating the phosphate ore. Excavation is quite an energy efficient operation considering the extremely large volume moved.

Pumps and pipelines are used to transport the phosphate ore as a slurry to the plant. Hydraulic transportation has been long established and is regarded as an efficient means of moving large tonnages of material. The power usage is largely dependent on the amount of water needed to achieve effective transportation, and the total distance the material is transported. Four functions primarily determine ore transportation energy consumption:

- Extent of pumping of water to the ore slurrying site.
- Water pressure required for slurrying of the ore.

- Water (or solids) content of the slurry pumped.
- Transportation distance.

Pumping of water to the site for slurrying ore is approximately 10% of the total transportation energy usage. Water pressure required to slurry the material is generally 30% of the total; monitor guns operate at 190-225 psig to achieve ore disaggregation. Actual slurry transportation of the ore consumes the remaining 60%. Approximately two thirds (by weight) of the transported slurry is water.

Total hydraulic ore transportation energy usage averages 5.00-7.00 kW-hr per ton, depending on conditions, which is approximately 70% of the entire mining area energy requirements.

Another type of ore transportation which was recently introduced to industry operations is an overland conveyor belt system traveling at 885 feet per minute. The total installed system is more complex since several steps occur in the ore transportation. Transport of water to the slurry site and pressurization of the water is still required since a conventional slurry pit and ore pumping is the initial step. Following this, a preliminary separation of clay waste by hydrocycloning is conducted near the mine, which consumes power, yet eliminates transportation of the waste clay and accompanying water. The operation dewaters the ore for transport by conveyor to the mill area. Precise energy consumption of this new approach has not been released; however, it could be speculated that energy consumption for ore transportation could be reduced fifty percent.

Other forms of transportation, such as trucks and loaders, are utilized in some small operations, but have not been shown useful for large systems (those producing over 2,000,000 tons per year ore). The variables of these systems are too great to estimate energy consumption. Generally, mobile units in small tonnage operations are greater in unit energy usage than the more conventional transportation system, but capital cost, etc., offset this consideration. Very large ore trucks can be competitive for smaller mines with short haul distances.

Mine support equipment such as trucks, bulldozers, and payloaders consume energy at a rate of less than 0.02 gallons of fuel per short ton of ore.

Washing and Feed Preparation

The function of the washing and feed preparation facilities is to separate ore into pebble, feed, and clay fractions. Clay characteristics and quantity is a determining factor in power requirements. Tough and/or excessive clays require more attritioning and more water for desliming.

Power consumption may be estimated on the basis of 3.9 kW-hr per short ton of ore; however, actual consumption will vary due to differences in matrix composition and flowsheet design.

Flotation

The function of flotation facilities is to separate feed into phosphate concentrate and sand tailings. Feed richness does not materially affect power requirements and consumption can be estimated on the basis of 9.0 kW-hr per short ton of flotation plant feed.

Drying

Fuel requirements for drying phosphate rock are approximately 410,000 BTU per short ton dry product. This fuel requirement is based on drying rock which has been drained to about 13% moisture to a shipment moisture of about 2.0-2.5% by weight. Fluid bed dryers are used for maximum efficiency.

Some modern phosphoric acid plants grind the rock wet and feed it to the acid digester without drying. The water in the rock is utilized in the chemical reaction to produce phosphoric acid. This, of course, is more energy efficient providing the chemical plant is located reasonably close to the mill so that transportation energy is not excessive.

Waste Disposal and Water Recirculation

Sand tailings and dilute clay slurries are the waste products of phosphate mines, and constitute a major percentage of the weight of the ore originally mined. In the typical case previously discussed, the sand and clay waste represented 75% of the dry weight of the ore, and this can be expected to increase in the future.

These wastes must be returned to the mined-out areas for disposal or use as backfill to accomplish land reclamation. The ton-miles and energy requirements are a very large component of total mine energy consumption.

Transportation of the clay slurry is usually by lift stations and open gravity-flow ditches, but the 3-5% solids slurry outflow is primarily water which must be recovered after clarification in the disposal area and returned to the plant. Water return is by gravity or pumping. The total system of clay disposal and water return is usually very energy efficient with pumping minimized.

Tailings are pumped as a slurry to mined-out areas for placement. Careful selection of disposal areas, pumping distances, and general operational planning are employed to minimize tailings pumping costs as part of total waste disposal/reclamation.

Dam construction, reclamation, and other ancillary equipment is generally diesel driven. Large or heavy equipment is used to minimize costs and energy consumption.

Estimates of energy consumption for waste disposal and water re-
circulation are very complex and dependent on many variables. Each mine
has specific factors which affect the unit energy consumption; however,
ore composition, pumping (or transfer) distances, and operational methods
are the major factors controlling energy consumption.

Reclamation Requirements

Reclamation of all land to be disturbed by phosphate mining operations
in Florida became mandatory by state law on July 1, 1975. For the four
years prior to this date, phosphate companies received rebates of up
to 50% of their paid-in severance tax (see regulatory requirements)
to cover costs incurred in state-approved reclamation projects. Before the
implementation of these direct regulatory incentives, phosphate companies
or subsequent owners reclaimed derelict land as economics or social
responsibility dictated. As of 1976, the Florida Phosphate Council
estimated that 30,500 acres of disturbed land had been reclaimed and that
reclamation was underway on an additional 15,000 acres. Methods of reclaim-
ing disturbed land have been developed over the years in response to the
various types of land forms remaining after mining. These methods have
generally incorporated economics and technical feasibility as their basis
and they form the state-of-the-art technology in the field. Social
consciousness by both the public and industry sectors is resulting in
rapid sophistication of these methods, but they will remain as the basic
approach to rehabilitation, particularly of derelict lands.

Physical Restoration Methods

Physical restoration techniques currently employed by the Florida
phosphate industry involve either the grading of spoils to form shorelines
around water-filled mine cuts or refilling the voids with wastes from the
beneficiation process. Reclamation is therefore closely related to waste
disposal. Backfilling of mined voids traditionally has been either with
tailings sand or clay wastes. More recently techniques have been developed
for using a mixture of the two waste materials as a landfill. Overburden
has been hauled as a backfill on a small scale (due to cost), generally in
response to regulatory requirements or community projects.

Water Body Construction

Mine cuts left by the strip mining process become filled with water
soon after mining, providing the confining substrate is not breached and
the water table level is reestablished. Contouring of overburden windrows
cast by draglines to form land and lake areas was one of the earliest
reclamation techniques employed. In this technique, bulldozers and pans
are used to grade the spoil piles to more gentle slopes as required by
state and county regulations. Proper construction of lakes requires
detailed engineering to insure that the reclaimed lakes will conform to
on- and off-site drainage requirements, once water table reestablishment

is complete. Frequently reclamation lakes are used as part of the mine water recirculation system during the active mining phase of the operation, hence must serve both operational and post-reclamation water use needs.

Soil stability of the land areas formed from spoils is generally acceptable for residential and light industrial construction. Several reclaimed lake areas have been developed as residential communities. Reclaimed lakes have also been used as water reservoirs for irrigation, aquatic wildlife/recreational areas, and as aesthetic contributions to surrounding reclaimed land.

Past reclamation methods as well as existing state and local regulations for reclaiming phosphatic lakes have come under criticism from those who believe insufficient attention has been given to the ecology of these areas. Depth and configuration of the resulting lakes varies depending on the original overburden and matrix thickness, and many reclaimed waterbodies are deeper and have narrower littoral zones than natural Florida lakes. Littoral zones are regarded by biologists as the most productive portions of lakes, and as a key element in a balanced ecosystem. There is also biological evidence that deeper areas may become anaerobic and as such, a potential hazard to the lake or drainage system since an inversion could bring this zone to the surface. These factors illustrate the level of public attention being given reclamation methodology, and the growing levels of technical sophistication necessary in the various disciplines utilized in restructuring the land.

Sand Tailings Fill

Backfilling mined-out cuts with tailings sand from the froth flotation process is accomplished by hydraulically transporting it from the flotation plant to the landfill site. The level of filling may be adjusted to establish the desired post-reclamation drainage and water table character-istics. Tailings sand dewaters rapidly and filled areas can support grading machinery almost immediately. It is a commonly applied practice to cover tailings landfills with overburden material from protruding spoil piles or nearby areas in order to improve soil fertility, structure, and moisture retention. Pans and/or bulldozers are used to spread the over-burden material to the desired thickness. Whether capped with overburden or not, tailings landfills have bearing strength acceptable for most construction and have been used for residential and industrial sites. The predominant land use of these areas, however, has been controlled by their location, which generally dictates their use for agricultural purposes.

Clay Fill

A substantial percentage of the area mined is subsequently used for the disposal of clay wastes produced from the ore separation-washing process. Since the impounded clays occupy considerably more volume due

to water entrainment than in their natural state, and release water very slowly, it has been necessary to construct retaining dikes and store a significant portion of the clays above natural ground level. Current methodology for reclaiming clay settling areas consists of promoting surface drainage in order to dry and form a surface crust layer. Initial drainage often consists of a perimeter ditch dug by a small dragline perched on the retaining dike. As the surface bearing strength increases, internal drainage ditches are installed and maintained using plows pulled by special low ground pressure vehicles. Differential subsidence of the drying impounded clays requires a long program of drainage maintenance. When a crust of sufficient stability has formed, volunteer vegetative growth is cleared using wide track bulldozers or heavy bushhog type rotary cutters drawn by low ground pressure vehicles.

The subsidence and crust development phase of settling area reclamation may require a period of several years. Generally land clearing and seedbed preparation can proceed in the drier areas during this phase. When the crust development is complete, the retaining dikes are spread towards and away from the impoundment to conform to regulatory slope requirements and produce a smoother landscape. Some of the dike material may be used to fill any depressions still persisting in the settling area itself.

Once surface drainage is established, phosphatic clays are a very favorable medium for plant growth. Due to their content of apatite, dolomite, and microcline feldspar, the clays have high levels of plant available Ca, P, Mg, and K. Their high content of silt and clay, particularly montmorillonite, gives them excellent water holding capacity. This same dominance of clay, however, makes them difficult to cultivate and prone to waterlogging during periods of wet weather. Moreover, the poor stability of subsurface clays handicaps the use of reclaimed settling areas for construction purposes. Consequently, reclaimed settling areas have been used almost exclusively for agriculture, primarily and most successfully as grazing land.

An alternative to the crust development technique is the use of a tailings sand layer to cap the clay settling areas. This method is distinct from sand-clay mix techniques since its goal is to establish a sand layer cap rather than a mixture of sand and clay. Sand from a tailings disposal pipeline is introduced into a deactivated settling area and the pipeline advanced as the sand layer forms. Typically, mud waves of clay form ahead of the advancing sand and form ridges of clay. Final grading eliminates pockets and ridges, and may spread the perimeter dike material over the settling area.

Clay settling areas capped with a thick layer of sand have revegetation disadvantages, but surface stability of these areas is somewhat improved. The real advantage of this technique is that it reduces the time period required to achieve surface stability.

Sand-Clay Mix Fill

Using a mixture of sand and clay to backfill mine cuts is a recent reclamation innovation by the phosphate industry. Many past attempts to use such a mixture have been hindered by the tendency of sand particles in suspension to separate and settle much more rapidly than clay particles, hence preventing the achievement of a homogeneous backfill. Sand-clay mixing techniques are the result of considerable applied research by both the industry and government agencies.

The following three techniques have shown promise:

Sand Spraying: Sand tailings are sprayed over naturally prethickened (12-15% solids) clays and the resultant compaction and channeling releases water. The clays are placed in mined-out cuts for prethickening, and therefore detailed planning and scheduling of events are required.

Flocculation-Mix: Chemical flocculants and thickeners are utilized to dewater the clay slurry to about 12% solids. The thickened clay slurry is used to repulp dewatered flotation tailings, and the mixture is pumped to waste disposal areas for further settling. This technique promises simplified water management because of rapid water recovery.

Dredge-Mix: Prethickened clay, dredged from settling ponds, would be mixed with dewatered sand tailings and pumped to mined-out cuts. This technique permits independent operation of desliming and flotation facilities.

The development of these techniques has had considerable support and funding because of the attractiveness of sand-clay mix as an alternative to traditional above-grade clay impoundment, and lower usage of water resources. The use of sand-clay mix as landfill may allow reclamation to proceed at a more rapid pace since the mixture dewaters and stabilizes more rapidly than the clay alone.

Properly mixed sand-clay soils are expected to have excellent agricultural potential. The clay fraction imparts fertility, nutrient-retention properties, and water holding capacity to the soil while the sand contributes tillage and aeration qualities. Soil stability is superior to clay soils but probably inferior to sand tailings landfills and the recontoured spoils associated with lake areas.

Sand-clay mix research continues to have high priority with the industry. Field scale applications are presently limited but growing rapidly. Improvement in feasibility and cost will no doubt be forthcoming as a result of this experience and concurrent research programs.

Overburden Fill

The overburden fill technique consists of filling mine cuts with overburden (spoil) hauled in from adjacent mining areas. This is an extremely expensive procedure, particularly if the haul distance is more than a few hundred yards. Accordingly, the method has been used only in cases of unusual economic incentive or commitment to specific regulatory requirements. Overburden fills can have excellent bearing strength and have been used for industrial sites as well as residential developments.

Revegetation - Land Use Alternatives

Florida law requires that all reclaimed land be adequately revegetated to stabilize the soil and prevent erosion. Regulations do not, at present, stipulate the nature of the vegetation required. Areas reclaimed as citrus groves would, for example, be considered 100% revegetated provided citrus trees are planted in normal commercial densities. Phosphate companies are, therefore, free to choose revegetation methods in accordance with the limitations of reclaimed soils and sound agronomic practices.

Revegetation of disturbed Florida phosphate land is not so severe a problem as revegetation in most other mining areas. Phosphate mining operations unearth no phytotoxic substances as is the case in certain mining operations. Of the mining wastes used to backfill mine cuts, only tailings sand presents problems to subsequent revegetation. The problem in this case is one of inherent infertility rather than toxicity. Vegetation can be established on tailings sand soils providing rainfall is adequate and a proper fertilization program is followed. The other backfill materials are acceptable plant growth mediums and frequently are more inherently fertile than the native leached sandy soils. Sand-clay mix soils are expected to be especially desirable in this regard.

Revegetation is closely related to the intended use of reclaimed land. Revegetation/land use alternatives are themselves dependent on the properties of reclaimed soils. Common revegetation/land use alternatives are shown in table 5 in relation to each of the landfill alternatives previously discussed.

Pasture

The majority of the land reclaimed by the phosphate industry to date has been planted in pasture grasses. There are several reasons for this predominance of pasture plantings. First of all, forage species can be selected that will grow on all reclaimed soil types, although level of productivity as well as species selection varies considerably for the various soil types. Secondly, pasture plantings are an excellent means of establishing a vegetative cover to prevent erosion, thereby satisfying regulatory requirements. Finally, cattle production is one of Central Florida's agricultural mainstays and reclaimed pasture land is very much in demand among Central Florida cattlemen.

TABLE 5. - Revegetation/land use possibilities for various landfill types

Landfill type	Pasture	Forestry	Citrus	Cropland	Residential/ industrial	Wetlands
Tailings sand fill........	+	-	-	-	++	-
Tailings sand fill capped with overburden..	++	+	+	+	++	-
Clay fill.................	++	-	-	+	-	++
Clay fill capped with sand..............	+	-	-	-	-	-
Sand-clay mix fill...................	++	++	-	+	-	++
No fill (land and lake areas).............	++	++	+	+	++	+
Overburden fill...........	++	++	+	+	++	-

- Landfill type not acceptable for revegetation/land use alternative in majority of cases.
+ Landfill type acceptable for revegetation/land use alternative in some cases given proper site selection.
++ Landfill type acceptable for revegetation/land use alternative in majority of cases.

Forestry

Tree plantings on reclaimed land have largely been restricted to scattered plantings in pasture areas. Some reclaimed soils are, however, favorable mediums for tree growth. Overburden soils, in particular, have demonstrated an ability to support a diverse growth of native trees. In some of the older mining areas, volunteer oaks, pines, sweetgums, etc. are now reaching maturity on overburden spoil piles. Where surface drainage is adequate, sand-clay mix soils are expected to be excellent mediums for tree growth.

Commercial forest plantings on reclaimed land have not been popular with the industry in central Florida, as it is not a traditional wood production area. Pine plantings in central and south Florida do not produce the cordwood tonnage expected in north Florida plantings. Furthermore, the wood processing yards are concentrated in the northern part of the state and the shipping differential results in a lower price for central and south Florida pulpwood. There is some speculation that commercial eucalyptus plantings in central and south Florida have potential and some phosphate companies have made pilot plantings on both reserve and reclaimed land. The market potential remains unclear at this time and no commercial plantings have been made in the phosphate area.

In all probability, commercial forest plantings will be a revegetation option infrequently used by the phosphate industry in the southern area, but may be a common designated land use for the Northern district. In addition, increased tree plantings for aesthetic and environmental purposes can be expected in the future. Some regulatory agencies have criticized the current practice of planting pasture grasses over large areas with only a few scattered tree plantings. Environmentalists contend that these ruderal expanses provide no cover for wildlife and have suggested planting clusters of relatively dense tree strands within such areas. Since these plantings will serve aesthetic and environmental purposes, native species will probably be favored.

Citrus

A few citrus plantings have been made on reclaimed land. Most of these plantings have been either on tailings sand sites or very sandy debris sites, above the natural water table. As a rule, these plantings have performed poorly due to the infertile and droughty nature of these soils. Citrus culture requires a soil with good internal drainage; therefore, clay soils are not suitable. A few plantings on overburden soils have shown promise.

Phosphate companies are oriented towards mining rather than agriculture. Based on present economics, most have not been inclined to make the substantial capital investment necessary for developing citrus groves on reclaimed land.

Cropland

Very little phosphate land has been reclaimed for row crop production.
The agriculture of the traditional mining area of central Florida is not
oriented toward production of row crops. Tailings sand soils are definitely
not suitable for this purpose. There has been at least one instance in
which topsoil has been hauled in to cover a tailings landfill and the site
subsequently used for the production of truck crops. There have also been
a few small scale truck cropping experiments on clay soils in an attempt to
utilize the fertility of these soils. These experiments have shown some
promise despite the difficulty in cultivating the clay. Properly mixed
sand-clay soils are expected to have excellent potential for row crop
production. As the sand-clay mix is perfected and the industry moves into
the more truck crop oriented areas in Hardee, Manatee, and DeSoto Counties,
the use of reclaimed land for row crop production may become more prevalent.

Residential/Industrial

Traditional methods of revegetating land for use as residential or
industrial sites have been the same as for pasture areas: a ground cover
of grasses is established to prevent erosion. Future methods will probably
include more tree plantings for aesthetic improvement, particularly in the
case of residential developments.

Wetlands

Florida contains over 20% of the remaining wetlands in the United
States, and these areas have been rapidly depleted due to coastal
and residential development, agricultural drainage, and urban expansion.
The preservation of remaining wetland areas has become a primary concern
of certain public and governmental groups. In response, developing
techniques of restoring and revegetating wetlands is one of the primary
reclamation problems facing the phosphate industry today. Public concern
over wetland areas has led regulatory agencies to restrict mining of swamps
and marshes, or require demonstrated mitigative measures. One approach to
wetland creation is simply to create a shallow aquatic or hydric physical
depression and let the area revegetate naturally. The other approach is
to induce the desired aquatic vegetation in reconstructed shallow aquatic
environments. Accordingly, plantings of typical Florida wetland vegetation
have been included in ongoing experimental work. The relationship of
physical restructuring (topography-hydrology) to biological response such
as climax revegetation and faunal habitat is another example of the level
of technology to be pursued in future reclamation.

COST ESTIMATION

Production Costs

Economic viability is the primary factor determining the designation of mineral resources as reserves. The unit most commonly used to gauge the economic feasibility of recovering the phosphate resource is the operating cost per ton of product or production cost per ton. Production cost estimates are available for some of Florida's existing mines. Estimates of production costs for both existing and proposed mining developments ("C" deposits) have been assembled. In the case of the remaining identified phosphate deposits ("R" deposits) under the Minerals Availability System, production cost inform-ation was entirely lacking. The production cost of these deposits directly identifies their potential and priority for development. A means of estimating production costs was, therefore, necessary not only for providing required input for "C" deposits in the MAS system encodement, but as a means of classifying the resources by economics.

Cost estimates for "C" deposits were generally grouped according to the type of ore, age of the mine, etc., to provide the basic cost data required. The actual cost by specific operation was not encoded, but rather the cost classification was applied. A cost modeling procedure was used to supply cost data for "R" deposits. These cost estimating procedures are outlined in the following discussion.

Description of Typical Cases

Prospective developments must compete with existing operations under the prevailing price structure generally established by the capacity/demand relationship. In order to adequately define the factors affecting production costs, an effort was made to compile as much production cost information as possible on both existing and proposed mining developments. Published pro-duction cost information is scarce and accounting procedures variable, particularly in regard to unit or production areas. It was therefore necessary to gather confidential cost information from companies active in the field in common units or variables. To protect the confidentiality of the cost data obtained, contributing operations were grouped into six cases according to size, age, reserve characteristics, and production cost criteria. A production cost for a "typical" mine representative of each case was cal-culated by averaging actual or estimated costs for the mines so grouped. Key variables of each of the six cases are listed below:

Case I

- Large mine (3,000,000-5,000,000 product tons per year).
- Low matrix "X" in the 2.8-3.5 yards per ton range.
- High pebble-to-concentrate ratio (that is, pebble ranging from 40-50% of the total product).
- Average product BPL above 70%.
- Mine at least 10 years old.

Case II

- Medium sized mine (1,500,000-3,000,000 tons product per year).
- Reserve characteristics same as Case I.
- Mine at least 10 years old.

Case IIA

- Medium sized mine (1,500,000-3,000,000 tons product per year).
- Reserve characteristics same as Case I.
- Mine not more than 2 years old.

Case III

- Small mine (1,000,000-1,500,000 tons product per year).
- Reserve characteristics same as Case I.

Case IV

- Large mine (3,000,000+ tons product per year).
- High matrix "X" in the 3.8-4.5 yards per ton range.
- Low pebble-to-concentrate ratio (that is, pebble ranging from 10-20% of the total product).
- Lower BPL grade (67-68% BPL with higher MgO content).

Case V

- Small mine (1,000,000-2,000,000 tons product per year).
- Reserve characteristics similar to Case IV.

Cases I, II, IIA, and III represent existing mines with higher grade reserves typical of the active mining area in central Florida. Cases IV and V represent new or proposed mines with lower grade reserves typical of the areas immediately south, but applicable to other areas in the state. Table 6 summarizes production cost data developed for the six cases.

TABLE 6. - Mining and milling production cost summary

	Cost/short ton of product (dry, FOB, mill)					
	Case I	Case II	Case IIA	Case III	Case IV	Case V
Direct cost	7.502	8.195	7.915	9.605	9.014	9.751
Indirect cost...	0.506	0.643	0.540	0.835	0.503	0.800
Fixed cost	2.530	2.135	5.096	2.227	6.347	7.278
Total Cost	10.538	10.973	13.551	12.667	15.864	17.829
Other costs[1]	0.726	0.858	2.032	0.608	2.420	3.046
Grand Total	11.264	11.831	15.583	13.275	18.284	20.875

[1] Capital costs refer to depletion or royalties cost plus depreciation of capital facilities.

Table 7 is a more detailed itemization of costs for a Case I mine, and table 8 treats a Case IV mine.

Factors Affecting Production Costs

The detailed study of production cost data for existing and proposed mines led to the identification of the key factors affecting production costs. The two variables found to have the greatest influence on production costs were (1) phosphate ore richness (recoverable product per unit volume of ore) and (2) mine size (production rate).

Richness is usually expressed as matrix "X". In general, the more ore that must be processed to yield a ton of product, the higher the cost of production. Table 6 shows that the cost of production for Cases I through III, representing the lower matrix "X" ore bodies, is substantially lower than for mines with higher matrix "X" ore (Cases IV and V). Factors other than matrix "X" also influence production costs. Ore and mining factors are listed and briefly discussed below:

- Total "X" - Total "X" refers to the total yards of overburden plus ore which must be handled to produce a dry ton of product. Since draglines can move overburden very inexpensively, total "X" generally has a minor effect on production costs if the overburden is reasonably stable. If the overburden is sufficiently thick, larger draglines may be required which increase both capital and production costs.

- Concentrate to Pebble Ratio - Pebble is less expensive to produce than concentrate, so ore containing pebble is usually associated with a lower cost of production and better product recovery. Cost data shown in table 6 reflect this relationship.

- Matrix Clay Content - The clay content of the ore is significant because increased clay demands more extensive waste disposal and often affects the attritionability of the ore. Tough, heavy clays can slow pumping rates, reduce production, and contaminate bene-ficiation products.

- Feed Grade - Feed grade refers to the BPL concentration of the sand size material in the ore. In general the higher the feed grade, the lower the reagent cost incurred in producing a ton of con-centrate product.

- Total Depth - Total depth refers to the total depth in the operating pit which is the sum of the overburden and ore thickness. Generally the effect of total depth on production costs is minor up to depths of 70-80 feet. However, greater depths increase costs through overburden rehandling or larger capital expenditures for draglines.

TABLE 7. – <u>Production cost of typical large mine</u>
<u>in higher quality ore (case I)</u>

(cost summary by category)

	Cost $/ton of product (dry, FOB)	Cost $/ton of ore (dry, FOB mill)		
	Total operating	Mine	Mill	Total
Raw materials, utilities and support:				
Power.............................	1.900	0.188	0.281	0.469
Reagents........................	0.709	–	0.175	0.175
Fuel (gasoline & diesel)........	0.017	0.004	–	0.004
Fuel (fuel oil drying)1/........	1.000	–	0.247	0.247
Supplies........................	0.191	0.035	0.012	0.047
Mobile mine support equipment...	0.093	0.023	–	0.023
Outside services (dam construction and reclamation).	0.563	0.139	–	0.139
Direct labor:				
Operating.......................	0.919	0.125	0.102	0.227
Supervisory.....................	0.249	0.037	0.025	0.062
Plant maintenance:				
Labor...........................	0.314	0.039	0.039	0.078
Supervision.....................	0.157	0.020	0.019	0.039
Maintenance parts and supplies..	0.874	0.107	0.108	0.215
Replacement mine pipe...........	0.140	0.035	–	0.035
Payroll overhead (fringes, etc.)..	0.376	0.051	0.042	0.093
Sub-total direct costs..........	7.502	0.803	1.050	1.853
Administrative, technical, clerical labor...................	0.288	0.036	0.035	0.071
Payroll overhead (administrative).	0.072	0.009	0.009	0.018
Facilities maintenance and supplies	0.043	0.006	0.005	0.011
General overhead (including head office, charges, exploration, and research)...................	0.103	0.013	0.012	0.025
Sub-total indirect costs........	0.506	0.064	0.061	0.125
Total direct and indirect costs	8.008	0.867	1.111	1.978

See footnotes at end of table.

TABLE 7. – <u>Production cost of typical large mine</u>
<u>in higher quality ore (case I)</u> –
Continued

	Cost $/ton of product (dry, FOB)	Cost $/ton of ore (dry, FOB mill)		
	Total operating	Mine	Mill	Total
Local taxes........................	1.270	0.267	0.047	0.314
Insurance..........................	0.040	0.005	0.005	0.010
Interest on capital:				
Plant............................	0.480	0.024	0.094	0.118
Land.............................	0.465	0.115	–	0.115
Working..........................	0.275	0.034	0.034	0.068
Sub-total fixed costs..........	2.530	0.445	0.180	0.625
Cost of dry rock loaded into rail cars at the plant location (less other costs)2/...................	10.538	1.312	1.291	2.603
Royalties (or reserves cost)....	(3)			
Depreciation....................	0.359	0.018	0.071	0.089
Depletion.......................	0.367	0.090	–	0.090
Sub-total other cost	0.726	0.108	0.071	0.179
Grand total cost............	11.264	1.420	1.362	2.782

1/Rock may or may not be dried in all cases since phosphoric acid processes are now available for the use of wet rock. Cost presented is for dry rock.

2/Total of direct, indirect, and fixed costs (other costs not included).

3/Included under depletion.

TABLE 8. – Production cost of typical large mine
in lower quality ore (case IV)

(cost summary by category)

	Cost $/ton of product (dry, FOB)	Cost $/ton of ore (dry, FOB mill)		
	Total operating	Mine	Mill	Total
Raw materials, utilities and support:				
Power...........................	2.458	0.160	0.241	0.401
Reagents........................	1.712	–	0.279	0.279
Fuel (gasoline & diesel)........	0.018	0.003	–	0.003
Fuel (fuel oil drying)1/........	1.000	–	0.163	0.163
Supplies........................	0.209	0.026	0.008	0.034
Mobile mine support equipment....	0.099	0.016	–	0.016
Outside services (dam construction and reclamation).	0.424	0.069	–	0.069
Direct labor:				
Operating.......................	0.936	0.084	0.068	0.152
Supervisory.....................	0.255	0.025	0.017	0.042
Plant maintenance:				
Labor...........................	0.323	0.027	0.026	0.053
Supervision.....................	0.161	0.023	0.013	0.026
Maintenance parts and supplies...	0.909	0.074	0.074	0.148
Replacement line pipe...........	0.124	0.020	–	0.020
Payroll overhead (fringes, etc.)...	0.386	0.035	0.028	0.063
Sub-total direct costs...........	9.014	0.552	0.917	1.469
Administrative, technical, clerical labor..................	0.306	0.025	0.025	0.050
Payroll overhead (administrative)..	0.076	0.006	0.006	0.012
Facilities maintenance and supplies	0.043	0.004	0.003	0.007
General overhead (including head office, charges, exploration and research......................	0.078	0.007	0.006	0.013
Sub-total indirect cost..........	0.503	0.042	0.040	0.082
Total direct and indirect costs......................	9.517	0.594	0.957	1.551

See footnotes at end of table.

TABLE 8. – <u>Production cost of typical large mine
in lower quality ore (case IV)</u> –
Continued

	Cost $/ton of product (dry, FOB)	Cost $/ton of ore (dry, FOB mill)		
	Total operating	Mine	Mill	Total
Local taxes.....................	1.620	0.224	0.040	0.264
Insurance.......................	0.040	0.004	0.003	0.007
Interest on capital:				
Plant.........................	3.000	0.098	0.391	0.489
Land..........................	1.241	0.202	–	0.202
Working.......................	0.446	0.037	0.036	0.073
Sub-total fixed costs.........	6.347	0.565	0.470	1.035
Cost of dry rock loaded into rail cars at the plant location (less other costs)[2]...........	15.864	1.159	1.427	2.586
Royalties (or reserves cost)..	(3)			
Depreciation..................	1.800	0.059	0.234	0.293
Depletion.....................	0.620	0.101	–	0.101
Sub-total other costs.........	2.420	0.160	0.234	0.394
Grand total cost...........	18.284	1.319	1.661	2.980

[1]Rock may or may not be dried in all cases since phosphoric acid processes
are now available for the use of wet rock. Cost presented is for dry rock.

[2]Total of direct, indirect, and fixed costs (other costs not included).

[3]Included under depletion.

● Contaminant Content of Ore – Magnesium and insoluble iron and aluminum content of the ore also affects production cost. Dolomitic fragments or coating may cause problems in feed preparation or flotation, while high insoluble levels may cause flotation difficulties. High product contaminant content may drive production cost per ton up, through the exclusion of otherwise suitable ore or through additional process requirements needed to make the product acceptable.

Production rate is the second major factor affecting production costs. Many cost inputs into a mining operation are not directly proportional to size. As the production rate increases, the cost per ton for these relatively fixed costs decreases. All other factors being equal, larger mines in terms of volume production have the cost advantage. Table 6 shows the definite correlation between mine size and production cost.

Capital outlay was also found to have a profound influence on unit production costs, as related to interest on invested capital and depreciation of capital facilities. Capital requirements for ore, equipment and facilities have escalated rapidly in recent years; therefore, existing mines will incur interest and depreciation expenses on a much smaller base than newer or proposed mines. The initial capital investment on many existing mines has been largely depreciated. This was largely responsible for separating the higher production costs for the new existing mines grouped in Case IIA from those of the older mines with otherwise similar characteristics grouped in Case II.

Other miscellaneous factors also influence production costs. Long pumping distances require heavy expenditures for power, pumps, and pipe, therefore forcing production costs upward. Mine recovery, the percentage of the ore recovered from the mining pit, markedly affects total project economics through its influence on actual reserve costs and mine life. It is generally not a recognized major factor in direct production costs although it exerts an effect by influencing the frequency of pit moves, production rate, etc.

Prospects for Production Cost Escalation

In the vast majority of cases, prospective mining developments or other identified deposits ("R") have lower quality reserves than those typical of existing mines. This is especially true with respect to extremely cost sensitive factors such as matrix "X" and pebble to concentrate ratio. Production costs for these deposits will certainly be higher as a result. Interest and depreciation expenses on higher capital investment will also tend to increase production costs, particularly in the early years of mine life. Overall, production cost increases are inevitable as the existing mines are replaced by new mines mining lower grade ore.

Production Cost Model

Production costs for typical existing and proposed mines was well established from the cost study, but accurate estimates of production costs expected for the "R" deposits was needed to classify the resource. A means of estimating production cost from basic geologic and mine planning data available for these deposits was developed through preparation of a production cost model for the study. The model is based on cost accounting procedures commonly in use in the Florida phosphate industry and considers all the major factors affecting production cost. It is designed to predict production costs within at least a $\pm$20% degree of accuracy, with the accuracy a function of the quality and confidence of input data. The model provides a basis for comparing the economic viability priority of various deposits or may also be used to delimit ore quality within a particular deposit. It is applicable and was in fact tested by "C" deposits, but is especially useful in evaluating "R" deposits.

The model describes in detail methods for estimating twenty-eight distinct inputs contributing to production costs. Major cost inputs considered include power, reagent usage, mobile equipment, dam construction, direct operating labor, direct production supervision, maintenance labor, maintenance overhead, maintenance materials, general overhead, rock drying, taxes, depreciation, and interest on capital invested in both reserves and plant facilities. The model requires as input the information shown on table 9.

Since cost accounting by area (mine or mill) was needed for the MAS format, a cross reference was provided in the model for converting the calculated cost input units to the desired category cost units. For this ore cost identification, the model provides for converting costs per ton or tonne of product to cost per ton or tonne of ore. In this conversion, the exact factor depends on the matrix "X" and matrix density of the deposit. Production costs may also be distributed to mine and mill components according to percentage allocations derived by averaging several costs incurred in the mining and pumping operations were included as mine costs. Washer, feed preparation and flotation facilities were combined as mill costs. In cases where the distinction was not identifiable by location, as in general overhead, costs were assumed to be proportionately divided between mine and mill components.

The model was used to project production costs for all "R" resources in the study, with the exception of a few special cases, such as "hardrock" deposits. The results are illustrated in figure 41.

Capital Costs

In addition to projected production costs, capital investment required for developing a deposit is a major factor in determining the economic availability of the phosphate resource. As explained in the preceding

TABLE 9. – Basic data sheet for use in production cost model

Production data	Units
Pebble..	Tons
Total concentrate...............................	Tons
Pebble/concentrate ratio........................	Decimal equivalent
Total production................................	Tons

Mining data

Matrix depth....................................	Feet
Overburden depth................................	Feet
Total depth.....................................	Feet
Matrix density..................................	Lbs/cu ft
Matrix "X"......................................	Cu yd/ton product
Total "X".......................................	Cu yd/ton product
Tons matrix/tons product[1]/....................	Decimal equivalent
Matrix average pumping distance.................	Miles
Percent slimes in matrix........................	Decimal equivalent
Tons slimes/year or acre-feet/year..............	Tons or acre-feet
Tons of tailings/year...........................	Tons
Tailings, average pumping distance..............	Miles
Operating hours per year........................	Hours
Number of operating days/year...................	Days
Acres mined/year................................	Acres

Equipment data

Number of draglines.............................	Number
Size of draglines...............................	Bucket size in yards
Number of pumping systems.......................	Number
Number of washer trains.........................	Number
Number of flotation plant trains................	Number
Number of dryers................................	Number

[1]/(matrix "X")(density in tons/cu yd).

discussion, interest and depreciation expenses on invested capital are major contributing factors to production costs, particularly for new mining developments. Even if production costs for developing an ore body are acceptable, the capital investment required may restrict the field of interested investors, thus reducing the potential for exploitation of the resource. As with production cost data, capital investment is available for some existing mines and detailed estimates have been made for a few proposed mines. Capital cost requirements for developing "R" deposits were, however, very poorly defined.

Capital costs for development of specific ore bodies may be estimated by a detailed listing of the component materials, sub-contract services, and labor inputs required, followed by a summation of their costs. This is the most accurate method and is employed by individual mining companies. A detailed estimate requires relatively advanced process designs for the operation as well as considerable time and expense. This lack of data precluded the preparation of detailed capital cost estimates for each of the "R" deposits; therefore a model of obtaining reasonably accurate capital cost estimates based on geological and general mine planning data commonly available for these deposits was prepared.

Capital Costs of Typical Cases

As the first step in developing a method for making rapid capital cost estimates, the capital cost data gathered as a corollary to production cost data for the six typical production cost cases was analyzed. Capital cost investment for phosphate mining operations fall into two categories – 1) investment in reserves, and 2) investment in equipment and facilities, collectively termed plant investment. Table 10 summarizes capital cost data developed for the six typical "C" cases.

TABLE 10. – <u>Capital cost summary</u>

Case	Production (MM short tons product)	Reserves acquisition ($MM)	Mine and mill[1]/ ($MM)	Total ($MM)
I	3.42	16.69	16.83	33.52
II	2.15	4.80	6.50	11.50
IIA ...	2.80	20.38	75.00	95.38
III ...	1.23	3.81	3.87	7.68
IV	3.00	37.23	90.00	127.23
V	1.57	29.38	53.55	82.93

[1]/ Refers to sum total of all equipment and facilities.

Plant capital investments shown for Cases I, II, and III are depreciated figures since these cases represent the older existing mines. Initial and depreciated capital investment for these cases is relatively low and not at all indicative of requirements for new facilities. Capital costs for

Case IIA, newer existing mines, are not substantially depreciated and are much higher as a result. The costs in Cases I-III are not indicative of capital cost requirements for proposed mines of comparable capacity since they were designed to process higher grade ore. Capital costs shown for Cases IV and V are more indicative of capital cost requirements for "R" deposit mines. Recent detailed capital cost estimates for typical new mining developments with Cases IV or V characteristics were used as a basis. These detailed estimates were used in designating factors controlling capital cost in developing a model for making rapid capital cost estimates for "R" deposits. Tables 11 and 12 show a more detailed itemization of typical Case I and IV mines, respectively.

Capital Cost of Reserves

Capital cost of reserves can be a significant input to the total capital requirements for developing a phosphate ore body. In the past, Central Florida phosphate reserves were acquired through outright acquisition of land containing the phosphate ore (fee ownership). Quantity and quality of the underlying phosphate ore has been the primary factor in determining selling price. Cost per ton of recoverable product may vary considerably depending on factors such as total tonnage purchased and proximity to existing mines. Some of the more recent reserve acquisitions have involved mineral acquisition with fee ownership reverting to the original owners once mining is complete. With reclamation now mandatory by law and the increasing competition for land in Florida, such arrangements are likely to continue. Varying and mixed mineral interests, cost and terms of payment make it extremely difficult to develop generalized guidelines for estimating capital cost of reserves. Reserve cost is therefore a capital input which must be estimated on a case by case basis.

Factors Affecting Capital Cost of Equipment and Facilities

Capital cost requirements for plant facilities are, of course, related to production capacity of the mine, but may vary considerably for mines of equivalent production capacity. Many of the same factors that influence production costs also influence capital cost. Of primary significance is the constituency of the ore, notably its matrix "X" or Ratio of Concentration. Matrix "X" is defined as yards of ore required to produce one ton of dry product. Since both mine and major portions of the mill facilities are sized to process ore rather than product, a given facility can produce more product from lower matrix "X" ore than from higher matrix "X" ore. Conversely, a larger (and more expensive) mine is required to produce the same product tons from higher matrix "X" ore.

Other factors related to ore constituency also have considerable impact on capital cost requirements. Since at least the initial clay settling area is generally calculated as part of the capital cost, the clay content of the ore is cost related. The relative content of pebble-to-concentrate product in the ore determines the size and cost of the washer and flotation

TABLE 11. - <u>Capital cost of case I mine</u>

Capital costs were estimated or based on known data and summarized in the following table. All costs refer to book value (original cost minus depreciation) as of January 1, 1978.

	Capital cost ($ MM)
Reserves acquisition	
Exploration and development.........................	$ 1.34
Land acquisition (land reserves cost).............	15.02
Permitting and environmental......................	0.33
Sub-total reserves acquisition............................$16.69	
Mine area	
Roads...	0.05
Utilities...	0.78
Buildings...	0.05
Mine equipment:	
Prime movers (draglines).......................	2.61
Hydraulic water and ore transportation.........	1.31
Mine support equipment.........................	0.26
Miscellaneous..................................	0.16
Sub-total mine capital......................................5.22	
Total mine capital...$21.91	
Mill area	
Roads...	$ 0.07
Utilities...	0.38
Buildings (office only)...........................	0.15
Process units:[1]	
Washer...	3.03
Feed preparation...............................	1.01
Reagent storage................................	0.67
Flotation......................................	3.88
Water distribution and waste disposal.........	0.50
Wet rock storage, drying and shipping.........	1.01
Offsites[2]....................................	0.91
Total mill capital...$11.61	
Total reserves acquisition, mine, and mill.....................$33.52	

[1] Complete units including equipment ready to operate.

[2] Support facilities - shops, rails, laboratory, etc.

TABLE 12. - Capital cost of case IV mine

Capital costs were estimated or based on known data and summarized in the following table. All costs refer to construction costs in terms of 1978 dollars.

	Capital cost ($ MM)	
Reserves acquisition		
Exploration and development........................	$ 2.98	
Land acquisition (land reserves cost).............	33.51	
Permitting and environmental......................	0.74	
Sub-total reserves acquisition.............................		$37.23
Mine area		
Roads..	0.28	
Utilities..	4.18	
Buildings..	0.28	
Mine equipment:		
Prime movers (draglines).........................	13.95	
Hydraulic water and ore transportation..........	6.98	
Mine support equipment...........................	1.39	
Miscellaneous....................................	0.84	
Sub-total mine capital....................................		27.90
Total mine capital..		$65.13
Mill area		
Roads..	$ 0.41	
Utilities..	2.02	
Buildings (office only)............................	0.81	
Process Units:[1]		
Washer...	16.20	
Feed preparation.................................	5.40	
Reagent storage..................................	3.60	
Flotation..	20.70	
Water distribution and waste disposal...........	2.70	
Wet rock storage, drying and shipping...........	5.40	
Offsites[2].......................................	4.86	
Total mill capital..		$62.10
Total reserves acquisition, mine, and mill...................		$127.23

[1] Complete units including equipment ready to operate.

[2] Support facilities - shops, rails, laboratory, etc.

units required. Since washer facilities are less expensive per ton of production capacity than flotation units, capital costs tend to be higher for low pebble-to-concentrate ratio ore bodies.

Factors other than ore constituency also influence capital cost. Dragline requirements are influenced not only by matrix "X" but also by overburden depth, matrix thickness, and total depth in the operating pit. In general, deeper overburden, greater total depth, and higher matrix "X" will increase the size and expense of the dragline required to maintain a required production rate. The distribution of the ore and average distance from epicenter or plant location is also a factor in ore transportation. Deposits remote to existing transportation facilities require considerable expense in the construction of railroad branch lines and plant access roads.

Prospects for Capital Cost Escalation

Factors related to poorer ore quality that will cause future escalation of production costs will also drive capital costs upward. Less concentrated deposits will require larger, more expensive facilities to produce at a given rate. Lower pebble content of product will require heavier capital investment in more expensive flotation units. Higher content of magnesium and insoluble contaminants in the ore will require additional facilities to make the product acceptable.

Keen competition for competitive quality resources has driven reserve investment sharply upward in recent years, and coupled with permitting has required significant cash outlay considerably in advance of production return. Interest expense has commensurately escalated.

Capital Cost Model

Having identified the range of capital costs expected for new mining developments and the key factors affecting these costs, a rapid method for making capital cost estimates was developed. Actually two methods of making capital cost estimates are presented in the model: a short method for making estimates of total capital cost and a longer method for making estimates of total capital cost and the individual components. The shorter method was designed primarily for making preliminary estimates needed for classifying "R" deposits where input data is limited. The longer method uses more detailed input information and allows a break out of capital items or categories.

Short Method for Capital Cost Estimation

The short method makes use of a basic formula commonly used by cost estimators for scaling capital cost of a known case up or down in capacity. Matrix "X" and pebble-to-concentrate ratio are the only variables considered as affecting the mine capacity/capital cost relationship.

This simplification was judged acceptable in making preliminary estimates since these variables had been identified as the most significant factors affecting the relationship. The formula is given below:

$$\frac{\text{Capital Cost New Mine}}{\text{Capital Cost Base Mine}} = \left(\frac{\text{Capacity New Mine}}{\text{Capacity Base Mine}}\right)^{0.7}$$

The commonly accepted exponent for chemical plants is 0.6; however, our studies show better correlation for an exponent of 0.7. In order to utilize this formula, it is necessary to work from information on a base mine with a known capital cost, production capacity, matrix "X", and pebble-to-concentrate ratio. Cost information for the base mine is listed by key components and a summation of their costs. In the short method, the base mine information was taken from detailed capital cost estimates for typical new mines. Capital cost was established for a facility processing ore with certain ore characteristics at a given rate as shown below:

        Base Mine Capacity .... 3,500,000 Tons per Year
        Base Mine Capital Cost........ $110,000,000
        Base Mine Matrix "X".......... 4.6
        Base Mine Pebble Content...... 10-20% of Total Product
        New Mine Capacity............. 1,000,000 Tons per Year
        New Mine Matrix "X"........... 4.6
        New Mine Pebble Content....... 10-20% of Total Product

Working from these known values, it is possible to calculate capital cost requirements for a mine of a different capacity which is to process similar ore. The following example illustrates the use of the formula:

For mine of 1,000,000 short tons per year,

$$\text{Capital Cost Mine} = (\text{Capital Cost Base Mine})\left(\frac{\text{Capacity Mine}}{\text{Capacity Base Mine}}\right)^{0.7}$$

$$= (\$110,000,000)\left(\frac{1.0}{3.5}\right)^{0.7}$$

$$= \$45,800,000$$

In the vast majority of the "R" deposits, average matrix "X" of the ore bodies differs significantly from the base mine matrix "X" of 4.6. In such cases, it is still possible to use the short method formula providing the production capacity of the base mine is first adjusted to the new matrix "X". Since production capacity is inversely proportional to matrix "X", the following formula may be used in adjusting production capacity of the base mine to the new matrix "X".

Capacity Base Mine at New Matrix "X"

$$= (\text{Capacity at Base Matrix "X"})\left(\frac{\text{Base Matrix "X"}}{\text{New Matrix "X"}}\right)$$

For example, if new matrix "X" = 4.0,

Capacity Base Mine at Matrix "X" of 4.0

$$= (3,500,000) \left(\frac{4.6}{4.0} \right) = 4,030,000 \text{ short tons per year.}$$

The capital cost of a mine of given capacity at a matrix "X" of 4.0 may then be calculated using the standard short method formula with the production capacity of the base mine adjusted to 4,030,000.

Capital Cost 1,000,000 TPY Mine at Matrix "X" of 4.0

$$= (\$110,000,000) \left(\frac{1.0}{4.0} \right)^{0.7} = \$41,500,000$$

It should be noted that the short method formula applies only to deposits in which pebble content lies in the range of 10-20% of total product, as in the base case. Although this range is common to most of the deposits south of the Central district and in northern Florida, it is not the case for all "R" deposits. Correction factors for pebble ratios cannot be firmly established; the model incorporates a capital increase of 4% for cases where the pebble is less than 10% of the product. Conversely, for each 10% incremental increase in pebble content above 20% of total product, total capital cost estimates are decreased by 4%. These corrections are empirical.

Capital costs estimated by the short method include the cost of rock drying facilities and draglines. They do not include working capital, reserve costs, or site unique expenses such as railroad branch lines, plant entrance roads, bridges, etc. The short method does not provide a means of breaking total capital cost down into cost areas (washer, flotation, reagent storage, etc.). Total capital costs estimated by the short method may be broken down into cost areas according to the cost breakdowns described in the long method.

Long Method for Capital Cost Estimation

The long method of capital cost estimation developed for the model is based on a modified cost module[29/] approach. A study of the detailed capital

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[29/] K. M. Guthrie, W. R. Grace & Co. Data and Techniques for Preliminary Capital Cost Estimating. Chemical Engineering, March 24, 1969.

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cost estimates prepared recently for typical new mining developments revealed that the capital cost for a typical phosphate mine could be broken down into eighteen distinct cost modules. Figure 32 shows how these modules contribute to the total capital cost.

To briefly summarize this method, the nine cost modules which represent the basic components of a phosphate mining complex were designated as the Base Area Modules. Each of the Base Area Modules can contain up to eleven different cost elements with each element representing a percentage of the total module cost. The eleven cost elements are listed below:
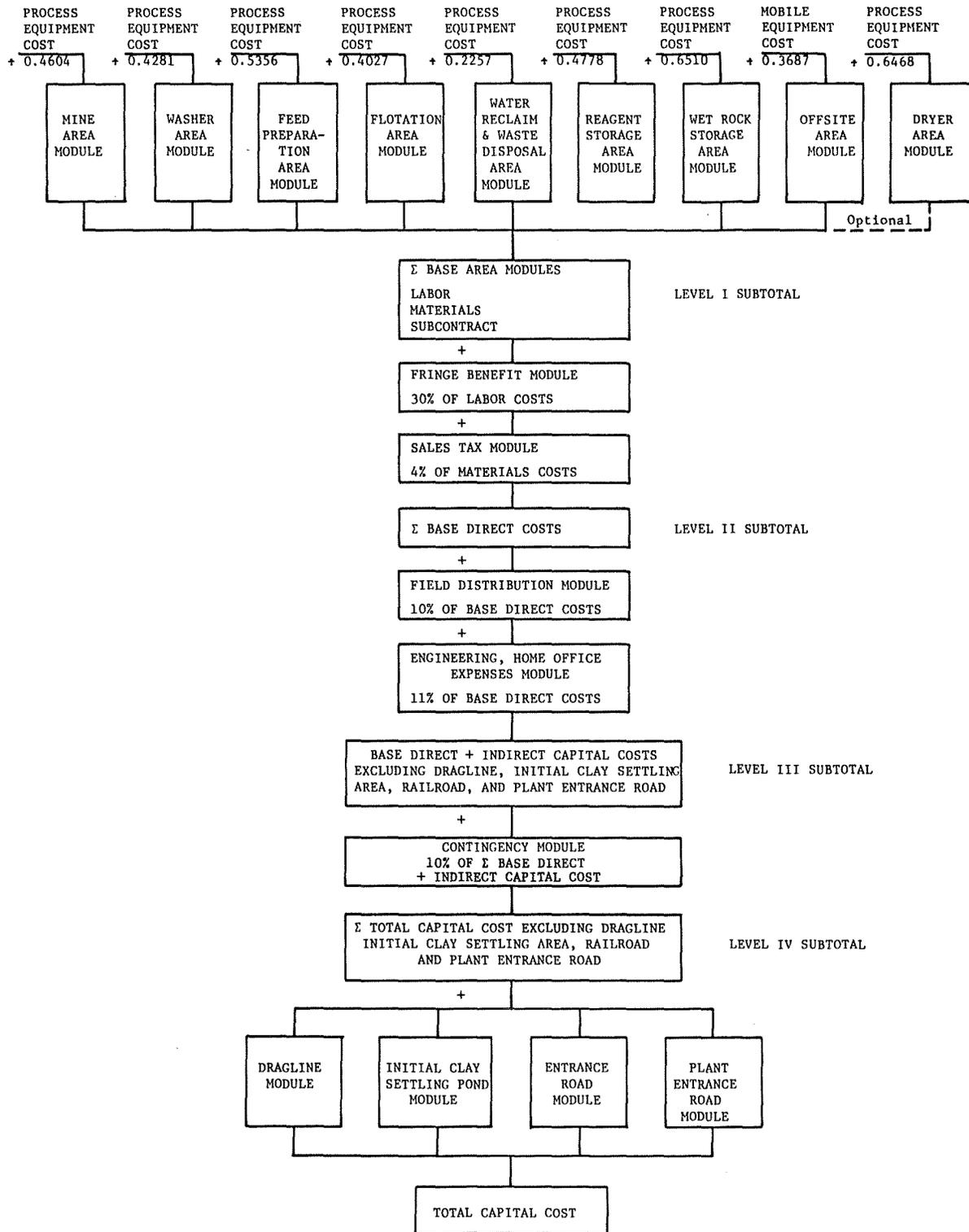
FIGURE 32.- Capital cost estimation using the module concept.

(1)   Process Equipment
(2)   Piping
(3)   Instruments
(4)   Electrical
(5)   Insulation
(6)   Painting
(7)   Concrete
(8)   Structural Steel
(9)   Buildings
(10) Site Preparation
(11) Mobile Equipment

The percentage contribution of each of these cost elements to their respective area modules was found to be reasonably consistent for all the cases studied.

The process equipment cost element was found to be a major input in all the Base Area Modules except the offsite area module. It was therefore concluded that in the eight Base Area Modules in which process equipment makes a major contribution, total module costs could be estimated by summing the process equipment costs for each of these modules and then dividing by the appropriate percentage contribution for process equipment in each case. For example, suppose process equipment costs for the Mine Area Module are determined to be $2,000,000. Dividing this total by 46.04%, the percentage contribution of process equipment to the total Mine Area Module costs, yields a total cost for the Mine Area Module of $4,344,000. In the Offsite Area Module, process equipment was not found to make a major contribution to the total module cost. For this module, total cost may be estimated by summing the mobile equipment costs and dividing by the percentage contribution of 36.87% this element makes to the total module cost. The Base Area Module Subtotal (Level I) is then obtained by summing the total costs of the nine Base Area Modules.

Each of the Base Area Modules may also be broken down into subcontract, labor, and material costs according to percentage contributions calculated for these costs in the cases studied. Using these percentages, the Level I Subtotal is broken down into a subcontract, labor, and material costs. The Fringe Benefits and Sales Tax Modules may then be calculated by taking 30% of the labor costs and 4% of the material costs in the Level I Subtotal. These cost modules are added to the Level I Subtotal to yield a Level II Subtotal for Base Direct Costs. Field Distribution and Engineering/Home Office Expenses Cost Modules are calculated by taking 10% and 11% of this Level II Subtotal, respectively, and these modules added to yield a Level III Subtotal for Base Direct and Indirect Costs. A 10% factor is calculated for this subtotal to yield the Contingency Cost Module. Adding the Contingency Cost Module gives a Level IV Subtotal consisting of the total capital cost excluding the Dragline Module, the Initial Clay Settling Area Module, the Entrance Railroad Module, and the Plant Entrance Road Module.

Costs associated with the final four modules were found to be very specific for particular deposits. Using capital cost data for the cases studied as a guide, methods were developed for estimating the cost of these four modules based on information specific to the particular deposit. Once these costs are determined, the total capital cost is derived by summing the costs estimated for these four modules with the Level IV Subtotal.

The long method requires more detailed input data than is available for most "R" deposits. In addition, it requires more time than is justified for the accuracy needed for this study. It can, however, be used as a check on the accuracy of the short method. To provide such a check, capital costs for three typical phosphate mines were estimated by the long method. The three examples were designated as Cases I, II, and III having the characteristics given in table 13:

TABLE 13. – Characteristics of example mines for capital cost

Characteristic	Case I	Case II	Case III
Production rate.............MM TPY....	1.5	3.0	4.5
Number of draglines...................	1	2	3
Size of draglines..........cu yd.....	45	45	45
Matrix "X".............................	4.5	4.5	4.5
Pebble content of product..percent...	10-20	10-20	10-20
Matrix density.............ton/cu yd.	1.35	1.35	1.35
% Clay in ore........................	25	25	25
Length of entrance r.r.....miles.....	1.5	2.0	2.5
Length of plant ent. rd....miles.....	1.5	2.0	2.5

Capital costs estimated for these three cases by the long method were compared with capital costs estimated by the short method, as shown in table 14 below:

TABLE 14. – Comparison of capital cost estimates by long and short methods

Case	Short method estimate ($ MM)	Long method estimate ($ MM)	% diversion from long to short method
I................	59.8	59.1	-1.2%
II................	97.2	102.8	+5.8%
III.............	129.1	141.3	+9.5%

This comparison using variously sized mines shows the two methods were found to agree within ±10%. It was therefore concluded that the use of

the short method would provide sufficient accuracy for the estimation of capital cost requirements for developing "R" deposits.

The long method also serves to provide a means of breaking total capital cost down into its component areas. Figure 33 depicts a capital cost breakdown derived by the long method. Except for the dragline, initial clay settling area, entrance railroad, and plant entrance road, the various cost modules may be factored from the total derived by the short method according to the various percentages shown.

```
                              ┌──────────┐
                              │  TOTAL   │
                              │ CAPITAL  │
                              │   COST   │
                              └──────────┘

┌──────────────────────┐
│   DRAGLINE MODULE     │
└──────────────────────┘              ┌─────────────────────────────────────┐
                                      │ CAPITAL COST EXCLUDING:              │
┌──────────────────────┐              │     DRAGLINE                        │
│    INITIAL CLAY       │              │     INITIAL CLAY SETTLING AREA      │
│ SETTLING POND MODULE  │              │     ENTRANCE RAILROAD               │
└──────────────────────┘              │     PLANT ENTRANCE ROAD             │
                                      └─────────────────────────────────────┘
┌──────────────────────┐
│  ENTRANCE RAILROAD    │
│      MODULE           │
└──────────────────────┘

┌──────────────────────┐
│   PLANT ENTRANCE      │
│    ROAD MODULE        │
└──────────────────────┘
```

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                                                    ┌───────────────────────────┐
                                                    │   CONTINGENCY MODULE       │
┌──────────────┐                                    │        9.09%*              │
│  SALES TAX   │                                    └───────────────────────────┘
│   MODULE     │
│   1.90%*     │                                    ┌───────────────────────────┐
└──────────────┘                                    │ ENGINEERING-HOME OFFICE    │
                                                    │   EXPENSES MODULE          │
┌──────────────┐                                    │        8.26%*              │
│   FRINGE     │                                    └───────────────────────────┘
│   BENEFIT    │
│   MODULE     │                                    ┌───────────────────────────┐
│   3.65%*     │                                    │  FIELD DISTRIBUTION        │
└──────────────┘                                    │       MODULE               │
                                                    │        7.51%*              │
                                                    └───────────────────────────┘
```

```
                  ┌───────────────────────────────────────────┐
                  │        BASE AREA MODULE SUBTOTAL           │
                  │  65.59% OF CAPITAL COST EXCLUDING          │
                  │       DRAGLINE, INITIAL CLAY               │
                  │        SETTLING AREA, ENTRANCE             │
                  │  RAILROAD, AND PLANT ENTRANCE ROAD         │
                  └───────────────────────────────────────────┘
```

MINE AREA MODULE 8.70%**	WASHER AREA MODULE 11.94%**	FEED PREPARATION AREA MODULE 11.19%**	FLOTATION AREA MODULE 12.01%**	WATER RECLAIM, WASTE DISPOSAL AREA MODULE 18.28%**	REAGENT STORAGE AND DISTRIBUTION AREA MODULE 1.20%**	WETROCK STORAGE AREA MODULE 18.28%**	OFFSITES AREA MODULE 15.47%**	DRYER AREA MODULE 12.09%**

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 * % OF CAPITAL COST EXCLUDING DRAGLINE, INITIAL CLAY SETTLING AREA,
   ENTRANCE RAILROAD, AND PLANT ENTRANCE ROAD.
** % OF BASE AREA MODULE SUBTOTAL.
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FIGURE 33.- Capital cost distribution.

REGULATORY AND ENVIRONMENTAL CONSIDERATIONS

Regulatory requirements for initiating and operating phosphate mining developments in Florida have become increasingly complex in recent years. The recent proliferation of regulations reflects the public's growing awareness and concern for its environment. Florida has a rapidly growing population including a large number of retirees not generally sympathetic to industrial needs. In the minds of many people, strip mining is not compatible with Florida's image or with its primary economic bases – agriculture and tourism. Public concern over strip mining has spawned a corresponding concern on the part of government agencies. Federal, state, and local levels of government are now directly involved in regulating the operations of phosphate mines.

Sensitive Issues

New mining developments, particulary those in areas where there has been little previous mining, have borne and can be expected to continue to bear the brunt of public scrutiny and regulatory constraint to the point of delay, postponement, or even prohibition. This factor plays a role in determining the availability of phosphate resources in the state. An identification of the areas of current public concern and regulatory involvement is essential to the determination of a deposit's potential for contribution to the state's phosphate resources. Concerns over the potential impact of mining on a region's environmental, cultural, and social resources cannot always be measured objectively, and resistance varies according to competition with other industry for resources, orientation of public attitude and economic need, as well as the ability of the area to absorb identifiable impacts.

Aesthetics

Many people object to strip mining purely on aesthetic grounds. Spoil piles left by the mining process are considered unsightly and industry critics have likened mined-out land to a "moonscape". A number of current reclamation methods and requirements are intended to mitigate these objectives.

Productivity of Reclaimed Land

At one time mining was believed by many to render land essentially useless from an economic standpoint (and it did). Industry reclamation projects in more recent years, particularly those involving residential or industrial developments, have served to promote the concept of "temporary land use". Most reclaimed land in Florida, either due to its nature or location, is suited primarily for agricultural uses. The natural productivity of reclaimed soils is receiving current attention, and ability to sustain vegetation is a minimum requirement. The ability of reclaimed soils to support vegetation compatible with the intended land use is an aspect of land use planning that is currently receiving additional study.

Wildlife Habitat

Strip mining naturally disrupts existing habitat, and there has been
further criticism that reclamation techniques have given insufficient
consideration to providing suitable replacement habitat for native wild-
life. Traditional methods of water body construction and improved pasture
plantings have received the greatest criticism. Modifications in
traditional methods are being instituted to address these concerns.

Wetlands

Environmental groups and some regulatory agencies are particularly
concerned about wetlands, which comprise a large part of the total land
area in some deposits. Marshes, both intermittent and permanent, as well
as swamps and extensive parts of river floodplains fall into the wetland
classification. These areas are of value for wildlife habitat, surface
water retention, nutrient assimilation, aquifer recharge, and sediment
removal. Florida contains over twenty percent of the total remaining wet-
lands in the United States, which have been reduced primarily by urbanization,
highway construction, and agriculture.

A mitigative approach for any company seeking to mine in wetland areas
is to prepare a conceptual plan for wetland construction based on best
available technology, as there has been little or no past demonstration of
intentional effective restoration. Wetland restoration, if approved, may
be quite expensive. Decisions to mine wetland areas are made based on the
value of the irreplaceable mineral resource underlying the wetland, the
difficulty of wetland replacement, the sensitivity of permitting, and the
true functional value to the site or region's resources. Presently, the
"sensitivity" and emotional public concern have made such discriminating
judgement difficult by all parties.

Waste Disposal

Traditional methods of clay waste disposal by above ground impoundment
slow the pace of reclamation and result in substantial water losses to the
recirculating system. In the past there have been several widely publicized
dam breaks which resulted in the contamination of nearby water courses.
There have, however, been no breaks of exterior dams built since engineering
and construction standards were adopted by the State in 1971, and regular
inspection and maintenance is required by law. Nevertheless, past experience
has caused companies seeking permits to mine in new areas to encounter wide-
spread concern over the settling pond issue. Mitigative approaches by
companies have included conceptual commitment to innovative reclamation
methods and building of secondary dams.

Water Use

Phosphate mining and beneficiation requires large volumes of water, as discussed in the mining water requirements section. Although this has been reduced and is being minimized by water recirculation and management and innovations in waste disposal, the potentiometric surface has been dropping in Central Florida in recent years. Mining developments must compete with agriculture and increasing urbanization for the water resources of the state. The combined effect of intense population growth and smaller groundwater resources along the coastal areas have intensified the problem and local resistance to additional water use. Commitments to recharge wells and use of surface water to satisfy a portion of the demand have been offered as mitigative approaches by mining developments in the permitting process. Extensive pumping tests have been required to establish the potential impact on the aquifer on both a local and regional basis.

Radiation

Phosphate ore typically contains variable amounts of uranium and its decay products. Most of this uranium is transported offsite in the severed phosphate product. A few operators have instituted uranium extraction procedures in the phosphoric acid processes. Some uranium residue, however, remains in the overburden spoils and in the sand and clay wastes. The potential health hazard associated with the radiation levels in reclaimed soils has recently received considerable study[24]. Radium-226, one of the

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[24] Kaufman, R. F. and J. D. Bliss. Effects of Phosphate Mineralization and the Phosphate Industry on Radium-226 in Ground Water of Central Florida. Office of Radiation Programs, U. S. Environmental Protection Agency, Las Vegas, Nevada, 1977, 136 pp.

Guimond, R. J. and R. A. Shaw. A Preliminary Evaluation of the Control of Indoor Radon Daughter Levels in New Structures. EPA-520/4-76-018, November 1976, 61 pp.

Mills, W. A., R. J. Guimond, and S. T. Windham. Radiation Exposures in the Florida Phosphate Industry (Draft). EPA Office of Radiation Programs, 1977, 238 pp.

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decay products of uranium, has received the greatest attention since its decay gives rise to radon gas, an identified carcinogen. U. S. Environmental Protection Agency studies have shown higher than background concentrations of radon gas in some structures constructed on reclaimed land. The potential health hazard to the occupants of structures on reclaimed land containing higher levels has led the EPA to publish suggested modifications in the construction of residences which will minimize the concentration of radon gas. Another study has shown higher radiation levels in citrus fruit grown on reclaimed land than in citrus grown on natural soil. The health hazard associated with the observed levels in this study is poorly defined. The significance of radiation levels of "reclaimed" land is under some dispute due to the poorly defined previous methods of "reclamation" and the fact that a great deal of undisturbed Florida soils are phosphatic and naturally exhibit comparable radiation levels.

Radiation levels vary considerably for the various reclaimed soils.
As a general rule, tailings sands exhibit lower radiation levels than clay
soils. Sand-clay mixture soils can be expected to exhibit levels in
between the two, depending on the relative proportions of sand to clay
and the uranium and radium contents of each. Observed levels in overburden
are particularly variable and dependent on vertical proximity to near surface
soils or content of the so-called "leach zone" strata of highly leached,
low grade phosphates.

At present, levels of radiation considered acceptable in reclaimed
soils are undergoing a definition stage. Mitigative measures, if deemed
necessary, appear feasible and the issue should be ultimately resolved.
It will remain, however, a component of future reclamation-land use planning.

Permitting

During the permitting process, prospective mining developments must
address all the issues discussed in the preceding section at all levels of
government involved. Table 15 lists the major permitting and regulatory
requirements that must be addressed.

Description of Permits

The potential impact of a mining development on the environment,
economy, or culture of a region is large and diverse, and when combined
with the public concern over issues previously described and the apparent
economic and aesthetic conflicts with Florida's image, acquisition of
permits for a new mining development becomes an intricate, protracted, and
expensive process. In addition, operating mines are being required to
operate under increasingly stringent parameters. This compliance is also
becoming a significant cost in the total process.

County Permits

Most Florida counties in which economic phosphate deposits are known
to occur have enacted mining or earthmoving ordinances to control mining
activities. These ordinances generally require that a zoning variance be
obtained reclassifying land into a mining or earthmoving category. Approval
of a zoning change is based on submission of a master mining and reclamation
plan. This plan must describe the mining site, the nature and extent of the
mining operation itself, and the proposed reclamation program.

For most phosphate mining developments, an Application for Development
Approval of a Development of Regional Impact (DRI) must be filed with the
county, prior to approval. The State Regional Planning Council (which
includes a number of counties) having jurisdiction reviews the DRI and
submits a recommendation for denial or approval to the affected county.
The county in turn considers the recommendation of the Regional Planning
Council as part of a public hearing that also may consider the zoning
variance and the master mining and reclamation plan. The county may elect
to follow or reject the recommendation of the Regional Planning Council.

TABLE 15. - <u>Permits and regulations pertaining to mining developments</u>

I.   County

   • Zoning Change
   • Master Plan Approval
   • Development Order
   • Operating Permit
   • Building Permit

II. State

   • Division of State Planning (through Regional Planning Council)
        Development of Regional Impact
   • Department of Environmental Regulation
        Air Quality Permit
        Industrial Waste Water Permit
        Dredge and Fill Permit
        Drainage Well Permit
        Dam Construction Permit
        Potable Water Supply Permit
        Sanitary Waste Permit
   • Water Management District
        Consumptive Water Use Permit
        Water Well Construction Permit
        Works of the District Permit
        Management and Storage of Surface Waters Permit
   • Department of Natural Resources
        Reclamation Standards

III. Federal

   • Environmental Protection Agency
        NPDES (Water Quality) Permit
        Air Quality Standards
   • Army Corps of Engineers
        Dredge and Fill Permit
        Dam Construction in Waters of the United States Permit

If the DRI, Master Plan, and Zoning Variance approvals are granted and a Final "Development Order" issued, an additional permit must be obtained prior to operations. This permit usually requires the submission of plans for any plants or dams to be constructed as well as a detailed implementation plan for the conceptual mining and reclamation program delineated in the Master Plan. Some counties also require the posting of reclamation bonds to insure compliance with reclamation standards and/or evidence of financial responsibility to indemnify the county or other parties for damages sustained as a result of ordinance violations. Operating permits are reviewed annually based on inspections by county officials and on progress reports filed by the permittees.

Several other minor permitting steps are generally required by local governments, including building permits, drinking water, waste disposal and public health regulations, and local environmental control (air and water effluent).

State Permits

Division of State Planning

State law enacted in 1972 requires a new mining company to prepare the Development of Regional Impact Statement previously mentioned. A Development of Regional Impact is required for a mining operation when it disturbs more than 100 acres annually or consumes more than 3,000,000 gallons of water per day. Consequently most new phosphate mining operations require the preparation of a DRI.

The review of a DRI application as previously mentioned is the responsibility of the Regional Planning Council for the region in which the development is proposed. The format consists of a questionnaire covering a broad spectrum of information requiring detailed response in such matters as the mine's description, the proposed reclamation program and schedule, and the effect of the development on the natural resources, transportation and economy of the region. To present the necessary information, a vast quantity of baseline data is collected on ambient air quality, surface water hydrology, groundwater hydrology, animal and plant surveys, and other detailed investigations. Most of the basic information compiled for the DRI is used for preparation of the county master mining and reclamation plan, federal EIS, and other permits. Close communication and coordination between the county, the planning council, and the applicant are required in order to facilitate the review process.

Department of Enviromental Regulation

The Florida Department of Environmental Regulation (DER) is also heavily involved in the permitting process for mining developments. DER regulations and permitting requirements pertinent to mining operations are listed as follows:

(1) Air Permit. A DER permit is required for construction of any stationary installation that can reasonably be expected to be a source of air pollution. In practice, phosphate rock dryers and storage and handling areas have required permits. Information on ambient air quality, estimates of emissions, and detailed abatement equipment or plans are generally required prior to issuance of a permit. Ongoing monitoring of emissions is usually a mandatory condition.

(2) Industrial Waste Water Permit. A permit from DER is required prior to installation of any stationary source of water pollution. In practice, beneficiation plants and waste water treatment facilities such as clay settling areas and water recirculation systems having discharge points have required permits. The "class" (intended water quality) of the receiving stream is considered.

(3) Dredge and Fill Permits. A DER permit is required before dredging and filling activities which will affect the following:

   (1) Rivers and their tributaries.
   (2) Streams and their tributaries.
   (3) Bays, bayous, sounds, estuaries, and tributaries.
   (4) Natural lakes.

Applicants are required to provide "reasonable assurance" that their activities will not violate water quality standards. Because of the wetland sensitivity that has recently risen, this permit is receiving considerable attention by the Agency.

(4) Drainage Well Permits. A DER permit is required for the construction and operation of a recharge well used to discharge sewage or surface water. This permit is applicable to those mines installing connector wells for mine drainage or as water use mitigative measures.

(5) Dam Construction Regulation. DER has established stringent guidelines for the construction, maintenance, and inspection of earthern dams used for above-ground storage of industrial wastes from phosphate mining and processing operations. Such dams must be designed by a professional engineer registered in Florida.

(6) Potable Water Supply Permit. DER requires that a permit be obtained prior to construction of wells used for the potable water supply of industrial concerns. Such wells must meet established construction requirements and the water must meet DER standards of quality for public water supplies.

(7) Sanitary Water Permit. A DER permit is required to construct or operate a sewage disposal system. Such a system must provide adequate treatment in accordance with DER rules and regulations.

Water Management Districts

The Florida Water Resources Act of 1972 provided for the creation of regional drainage districts throughout the state. These districts have adopted regulations dealing with water resources, both surface and underground. Regulations and permits pertinent to mining operations are as follows:

(1) Consumptive Water Permit. Consumptive use permits are required if the average daily withdrawal exceeds 100,000 gallons per day, if the withdrawal facility has a capacity of more than 1,000,000 gallons per day, or if the withdrawal well has an inside diameter of 6 inches or more. Consequently essentially all phosphate mining operations require a consumptive use permit. It has been the policy of the Southwest Florida Water Management District to require extensive hydrologic groundwater testing prior to issuance of permits for new withdrawal by phosphate companies. The intended consumptive use must be judged a "reasonable and beneficial use which serves the public interest" which does not interfere with any existing legal use of the water. Mitigation is encouraged, and applicants have been required to submit documentation as to need of the requested withdrawal rate. Permits may be denied if projected stream flow or groundwater levels fall below the levels established.

(2) Water Well Construction Permit. Permits are required for the construction of any water well and are issued to licensed water well contractors only.

(3) Works of the District. A permit is required to connect to, withdraw water from, discharge water into, place construction within or across, or otherwise make use of any work of the District. Works of the district include any water course or other facility either owned and maintained by the district or adopted by the Governing Board as a work of the district. Factors considered in permitting include whether the activity will encroach on the mean annual floodplain of a water course, whether the rate of flow of a water course will be altered, and whether adverse drainage or innundation affects will result on lands not owned by the applicant.

    (4) Management and Storage of Surface Waters. A permit is required for construction of dams which meet any of the following criteria:

        (1) Impound water on an area exceeding 40 acres.
        (2) Divert water from an area exceeding 40 acres.
        (3) Reroute or alter the flow of a stream which drains a watershed exceeding five square miles.
        (4) Rely on a water course for supply.

    The dikes of clay settling areas of phosphate mining operations may fall under this provision.

Department of Natural Resources

The State is directly involved in the regulation and supervision of land reclamation programs. The Department of Natural Resources sets standards which reclamation programs must meet and is responsible for monitoring and evaluating compliance as to water quality, timing, bank slopes, revegetation, and safety.

Federal Permits

Environmental Protection Agency

The Federal Water Pollution Control Act of 1972 established the National Pollutant Discharge Elimination System (NPDES) and prohibited discharge of waste water into "waters of the United States" without a NPDES permit. For all practical purposes any water course falls under NPDES jurisdiction.

Preparation of an Environmental Assessment Statement is required of all new sources prior to issuance of a NPDES permit. Based on this statement, the EPA determines whether the new source will have a significant impact on the environment. If so, the EPA must prepare an Environmental Impact Statement.

Criteria and contents for preparation of an EAS or EIS will vary somewhat with the development, and will become more structured and identifiable as they are submitted. Presently, no new source document has been submitted, although several are in the initial steps of preparation. Although the format will apparently differ from the DRI, most of the same basic information will probably be applicable. The EPA's review of the development has been broadened past potential effluent quality. EPA has recently completed an "areawide study" of Florida Phosphate Mining in preparation of an EIS, to include a "scenario" for operational compliance in other areas.

The Clean Air Act enpowered EPA to establish national ambient air quality standards. The setting of emission standards for hazardous pollutants and standards of performance for new stationary sources of air pollution also became the responsibility of the EPA. Regulations for

prevention of <u>significant</u> <u>deterioration</u> of air quality were established. Permitting remains a state responsibility although EPA approval may be required prior to construction of stationary air pollution sources.

Army Corps of Engineers

The Army Corps of Engineers is also involved in federal water quality regulations. Under the FWPCA (Section 404) a permit from the Corps is required for dredging and filling activities in the "navigable waters" of the United States. "Navigable waters" has been interpreted broadly to include not only water courses and their tributaries but also their contiguous or adjacent wetlands. Recent changes have been made in the Corps' jurisdiction and practically speaking their authority extends over all bodies of water, permanent or intermittent, and their drainage areas.

A permit is required if a dam is to be constructed on a navigable waterway. Most mines do not require such structures.

Costs and Time Requirements

Table 16 illustrates recent typical scheduling and cost of major permit acquisition for new phosphate mines in Florida which may require several years to complete. Presently, only two of the larger developments have sufficiently completed the process to begin construction; both of these were declared existing sources by the EPA. The term in the table "DRI Approval" refers to investigative, application, and public hearing requirements previously discussed.

Environmental permitting in Florida in the past five years has grown increasingly complex by rapid growth in regulation, overlapping agency jurisdiction, and accompanying confusion as to guidelines or requirements by both the applicants and reviewers. The outlook should be for procedural clarification, but continued regulatory control and public awareness of the industry as it coexists with Florida's growing population.

The present cost of permitting is sufficient to postpone activities as long as the development schedule will allow. Shifts in environmental priorities as the process proceeds, difficulties in requirement identification, public opposition, etc., all lengthen and disrupt the schedule, and commensurately increase costs. On the other hand, the ongoing environmental data collection and study may clarify certain issues and shorten site specific requirements. In any case, permitting will continue to affect the cost, scheduling, and even viability of deposit development.

The cost of monitoring the natural environment, pollution abatement equipment, and managing the operation to comply with regulations is a significant capital and operating cost. The environmental engineering costs, including land reclamation, coupled with Florida's severance tax will remain significant economic considerations.

TABLE 16. - Environmental permitting requirements

	Phase[1]	Air	Socio Econ	Hydrol	Waste water	Ecol	Water chem	Plan engr	Average pre-startup cost[2]
Monitoring - Studies, Reports									
Radiation Monitoring...............	I, V	X		X			X		$ 25,000
Fluoride, SO$_2$, Particulate.........	I, V	X						X	100,000
Water Quality......................	I, V				X		X		50,000
Clay Studies...................,...	I							X	20,000
Stream Flow........................	I, II, V			X		X		X	50,000
Biological, Archaeological Surveys.	I					X			50,000
Groundwater........................	I			X					350,000-1,500,000
Surveys, Photogrammetry............	I							X	25,000-50,000
Local/County Permits									
Mining Ordinance (Master Plan).....	I	X		X	X	X		X	75,000
Rezoning...........................	I								-
Building Permit....................	III							X	5,000
Mining Permit......................	IV							X	50,000
Regional									
SWFWMD (Water Use).................	I			X				X	50,000
SWFWMD - Works of District.........	III			X				X	10,000
DRI................................	I	X	X	X	X	X	X	X	250,000
State									
DER Air............................	II, V	X						X	30,000
DER H$_2$O Effluent..................	II, V				X		X	X	25,000
DER D & F..........................	II			X		X		X	50,000
DER Sanitary H$_2$O..................	IV						X		500
DER Dike Construction..............	I, III							X	75,000
DNR Master Reclamation Plan........	IV							X	50,000
Federal									
EPA-NPDES (EIS)....................	I, II	X	X	X	X	X	X	X	125,000
C.O.E. Dredge and Fill.............				X		X		X	25,000
Oil Spill Prevention...............	III								2,500
Air (Significant Deterioration)....	III								15,000
Total Cost									$1,558,000-3,733,000

1/
Phase I	Pre-DRI Approval
Phase II	Post-DRI Approval
Phase III	Design Engineering
Phase IV	Construction
Phase V	Operational

2/ Excludes management, legal fees, public relations.

Current Regulatory Developments

In addition to existing regulations and permit requirements, the following related areas warrant discussion:

- State Severance Tax Law Revisions
- Federal Surface Mining Control and Reclamation Act of 1977
- EPA Regional Environmental Impact Statement

State Severance Tax Law Revisions

Since July 1, 1971, a portion of the severance taxes paid by phosphate companies has been rebated to the companies for costs incurred in state-approved reclamation projects. Originally the severance tax rate was set at 5% of the established value of the mineral at the point of severance. The taxpayer was entitled to a partial credit against ad valorem taxes paid upon the assessed mineral value of the property upon which the site of severance was located, providing approved reclamation programs were in progress. In addition, up to 50% of the severance taxes paid was available for reclamation rebates. In 1975, legislation was passed requiring reclamation of all lands disturbed after that date. In 1977, the legislature increased the severance tax rate to 10% while holding the amount available for refund constant by reducing the rebate to 25%. The existing law was also changed to encourage rehabilitation of disturbed land not covered by mandatory reclamation laws by stipulating that rebates would only be made for reclamation of land mined before July 1, 1975 or for land included in a reclamation program filed before July 1, 1977. A special Phosphate Land Reclamation Study Commission was appointed by the governor to study the reclamation issue and on March 1, 1978 submitted its report to the governor. The report contained recommendations as to allocation of the 25% previously rebatable for reclamation of lands disturbed prior to July 1, 1975, or lands included in a reclamation program filed on or before July 1, 1977. In addition a new Phosphate Research Trust Fund was established to fund research in the phosphate reclamation field.

Federal Surface Mining Control and Reclamation Act of 1977

At present, this law applies only to coal mining operations and no legislation is pending that would bring phosphate mining under its jurisdiction. However, the bill states the need for the development of more complete information on the mining of non-coal minerals in order to formulate federal regulations to control such mining. A study, together with specific legislative recommendations shall be submitted to the president and Congress no later than eighteen months after the date of enactment of this act (Secs. 709a and b). In May 1977, the Comptroller General's Office completed a survey of the reclamation of lands disturbed by mining of non-coal minerals and of existing state legislation dealing with the reclamation of these lands. Their report to the Senate Committee on Energy and Natural Resources concluded that "federal leadership and assistance will be essential for the development of effective programs". Efforts to include phosphate mining under the provisions of this legislation can be expected; however, its potential impact on prospective mining developments is difficult to assess at this stage. It appears, however, that local and state standards concerning

reclamation are in general sufficient to the point that federal jurisdiction will not be an inhibiting factor, other than cost of permitting and compliance.

Regional Environmental Impact Statement

The EPA recently completed an environmental impact study of the effects of the phosphate industry on a seven county region of Central Florida. This study included a review of phosphate mining as it relates to the present and projected economy, environment, and land use patterns of the region. Several scenarios of government action were presented ranging from no action to a complete moratorium on new mining activities. Between these extremes, specific scenarios related to water conservation, process modifications, and development in wetlands were considered. A draft report was submitted in March 1978 by the Agency. Key EPA recommendations pertaining to new mining activities include minimization of rock drying facilities, meeting state standards for water discharges, minimizing conventional above-ground clay disposal areas, meeting Water Management District consumptive water use requirements, use of recharge wells in dewatering the shallow aquifer before mining so as to replenish water pumped from the primary (Floridan) aquifer, relating radiation levels of material obtained by test borings to proposed regulations to be published by EPA, including the DRI/EIS reports an inventory of wildlife habitats for the area immediately surrounding the site as well as on the site itself, and protecting or restoring wetlands of high environmental value. As previously discussed the industry is already in the process of meeting many of these recommendations. Public and industry input via public hearings, etc. will determine the final scenario. Strict compliance will, if deemed necessary, in some cases restrict the availability of phosphate resources, particularly in certain wetlands or where compliance would make economic feasibility marginal.

IDENTIFIED RESOURCES

Deposit Identification

Resource information for "C" operations was generally available from multiple sources, including questionnaire completion, corporate annual reports, 10-K reports, hearsay assessment, literature on mine life, etc. In most cases, the overlap of sources and agreement of data was sufficient to provide good confidence in resource estimates. For "R" deposits, the quantity and quality of information varied from published data to geologic inference. The majority of the data collected was based on deposit summaries furnished by the cooperating companies. These summaries included varying prospecting drill hole densities, but were, in general, sufficient to provide confidence in the accuracy of the resource data.

In northern Florida and in the east coast of Florida very few available deposit identifications have been previously made or quantified, with the exceptions of several company prospecting reports which were made available, Occidental published data, and the Osceola National Forest EIS. Some degree of success, however, was achieved by obtaining drill hole prospecting information from six companies that had prospected these areas in the 1960's, and more recent drill hole data from various private sources. The total number of holes for which prospecting information was collected for the North and East Coast areas is about 2,700. The distribution or density of prospecting over the area varies widely, with more than one source often providing data on a single locality.

In reviewing the drill data and reports for evaluation of the prospecting data, recognition criteria were used to identify phosphate deposits from phosphate occurrences. Most of the State of Florida is covered or underlain by Pliocene-Miocene phosphorites, with the primary concentrations occurring in the Hawthorn (Miocene), Bone Valley and Alachua (Pliocene-Miocene) formations. These formations contain sequences up to several hundred feet thick of phosphatic clays, sands and limestones in varying degrees of phosphate concentration, amenability to extraction from gangue, and product P_2O_5 and contaminant (magnesium, iron, aluminum) content. Various criteria used are considered a minimum level of stringency to establish "mineral concentration". Material below this level would be so marginal in concentration and quality that its inclusion would expand the "resource" to areas of size impractical to delimit vertically or horizontally; thus, the resources would be hypothetical rather than identified. The criteria used are, however, sufficiently loose to include resources properly categorized as sub-marginal in economics and/or technological extraction feasibility. Most past prospecting has not collected samples or derived resource estimation on occurrences below these criteria limits. The criteria were used as guidelines rather than absolute cutoffs, and their application did not exclude any significant known delimitable occurrences.

Currently Used Reserve Selection Criteria

Tables 17 and 18 list criteria submitted to the study by several mining companies that are used as acceptability standards for ore designation. For Central Florida deposits, the number of criteria applied to the phosphorite is limited, and reasonably standard. MgO contamination criteria are seldom used or required, because the ore is reasonably low in magnesium content. Matrix "X" (yards of ore yielding one short ton of product) or ore ratio of concentration criteria vary considerably, but are not necessarily meaningful as a rejection parameter because most of the ore is usually of acceptable product yield, especially when compared to new resources. Application of more stringent criteria to Central Florida ore does not necessarily eliminate resources, since the poor quality ore fraction is minor, resulting in good average ore.

The "South Florida" criteria in table 18 indicates a more comprehensive application of criteria by a number of the developers. When utilized in comparison to Central Florida acceptability limits:

- Product BPL values are generally lower.
- Matrix "X" values are higher.
- Flotation feed BPL values are similar.

These criteria illustrate the need to relax acceptability limits in order for the lower yield and quality ore in the southern district to be included in reserve estimates. Similar criteria would be applicable to the Northern district. Note that several additional criteria are also considered, including MgO content, total depth, percent clay and overburden thickness. The application of these criteria signify that the matrix is often deeper, physically tougher to attrition, and more dolomitic and/or limey than Central Florida. In the case of both the Central and South Florida criteria, acceptability criteria are noticeably accommodated to the deposit. The most important consideration given is its overall competitive quality and amenability to a reasonable extraction flowsheet. Notwithstanding those few deposits listed that have only minimal acceptability criteria, it becomes apparent that reserves or resource estimates offered by operators or developers cannot be easily extrapolated to larger or smaller figures by comparing them to criteria offered by competitors. The criteria applied are devised to meet individual operators' objectives and requirements in terms of deposit quality and process technology. The resulting ore body will be expanded or reduced in size to meet quality and/or economic restrictions during the life of the mine. The MAS probabilistic-grade matrix indicates this quality-size relationship.

Resource Criteria

Criteria are utilized by active mining companies and developers to determine a current reserve - that portion of the total phosphate resource that is economically extractable under current and projected cost structures.

TABLE 17. – <u>Central Florida mineability criteria</u>

Company	Pebble			Concentrate			Total product		
	> BPL	< I&A	< MgO	> BPL	< I&A	< MgO	> BPL	< I&A	< MgO
A	65.0	4.0	–	70.0	4.0	–	–	–	–
B-1....	64.0	–	–	68.0	–	–	–	–	–
B-2....	60.0	–	–	64.0	–	–	–	–	–
C......	60.0	–	–	66.0	–	–	–	–	–
D......	–	–	–	–	–	–	60.0	–	–
E......	–	–	–	–	–	–	60.0	–	–

	Min feed BPL	Max total depth	Maximum matrix "X"	Maximum total "X"	Min matrix thickness	Minimum tons/acre
A......	–	–	4.50	–	5.0'	–
B-1....	13.0	–	4.50	–	–	–
B-2....	13.0	–	4.65	–	–	–
C......	12.0	–	8.00	21.0	–	–
D......	12.0	–	5.00	20.0	–	3,000
E......	–	–	–	21.0	5.0	–

NOTE.--Matrix "X" – matrix yards processed per recoverable ton of product.
Total "X" – matrix plus overburden yards moved per recoverable ton of product.

TABLE 18. - <u>South Florida mineability criteria</u>[1]

Company	Pebble			Concentrate			Total product		
	> BPL	< I&A	< MgO	> BPL	< I&A	< MgO	> BPL	< I&A	< Mgo
A	-	-	-	-	-	-	60.0	-	-
B......	58.0	3.5	1.0	64.0	3.5	1.0	-	-	-
C......	55.0	-	-	65.5	-	-	-	-	-
D......	-	-	-	-	-	-	-	-	-
E-1....	-	-	-	62.0	-	-	62.0	-	-
E-2....	60.0	-	-	68.0	-	-	-	-	-
F......	58.0	-	1.5	62.0	-	1.2	-	-	-
G......	59.9	-	-	61.9	-	-	61.9	5.0	-
H......	58.0	4.5	1.5	62.0	4.0	1.2	60.0	4.0	1.2
I......	58.0	3.5	1.0	64.0	3.5	1.0	-	3.5	-
J......	-	-	-	-	-	-	-	-	-
K......	-	-	-	65.0	3.5	1.5	65.0	3.5	1.5
L......	60.0	4.0	1.5	64.0	3.5	1.2	-	-	-

Company	Min feed BPL	Max total depth	Max matrix "X"	Max total "X"	Min matrix thick	Min TPA	Max % clay	Max O/B thick
A......	12.0	-	7.00	20.0	-	3,000	-	-
B......	12.0	-	8.00	-	5.0	-	-	-
C......	12.0	-	-	20.0	-	-	-	-
D......	10.0	-	10.00	21.0	-	-	-	-
E-1....	-	100.0	5.36	-	-	-	-	-
E-2....	15.0	-	4.80	-	-	-	-	-
F......	12.0	100.0	7.00	-	-	2,500	35.0	-
G......	12.0	-	8.00	21.0	5.0	-	-	-
H......	12.0	100.0	7.10	20.0	5.0	3,000	37.5	-
I......	12.0	120.0	8.00	-	5.0	-	-	65.0
J......	10.0	-	10.00	21.0	-	-	-	-
K......	-	-	8.00	-	-	-	-	-
L......	12.0	135.0	8.00	20.0	-	-	-	-

[1]/Includes Hardee, Manatee, DeSoto, and Sarasota Counties.

The lower quality material remaining is a "resource". Guidelines that have been employed by the USGS to establish a minimum criteria for recognition of a phosphate rock as a resource containing greater than 20% P_2O_5[33/] are too broad for the purpose of this study. On the other hand, any set of imposed

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[33/] Cathcart, J. B. and R. A. Gulbrandson. Phosphate Deposits in United States Minerals Resources, U. S. Geol. Survey. Professional Paper 820, 1973, pp. 515-525.

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guidelines will establish a rejection process for inclusion of a phosphate occurrence as identifiable. Such a criteria imposition rejects all other occurrences as resources, although hypothetically any concentration can be extracted at some cost. Table 19 lists guidelines used for identification of a phosphate occurrence as a deposit in order to establish feasible limitations on the study in terms of deposit identification.

The size of the occurrence is pertinent from the standpoint that there must be sufficient extractable reserves to support production for a reasonable amortization period; for example, a 500,000 tons per year plant with a minimum depreciation period of 10 years requires a reserve of 5,000,000 tons. Currently, the 500,000 tons per year operation for certain ore bodies is considered the minimum production rate which will absorb fixed costs and remain competitive. Exceptions to this are certain small scavenger operations and mines within the Hardrock district, both of which may require less capital investment and produce at economic costs due to special ore characteristics.

The minimum acceptable size of an ore body was related to the average overburden thickness. Overburden thickness dictates prime mover size and equipment investment necessary to meet production objectives and absorb the larger fixed costs and depreciation. There can be notable exceptions to these guidelines, dependent on ore richness and quality.

Concentrate product grade is established at a 60% BPL minimum. There is an extremely large resource available at this grade level in terms of both a domestic and world availability, and grades below this are unlikely to become marketable in the forseeable future. A minimum grade of 50% BPL for pebble product was applied since it is recovered while producing concentrate and it is a small proportion of the separated phosphate in all ore bodies except in the Central district. Beneficiation techniques may be utilized to upgrade some portion of this low grade pebble to more acceptable grade levels.

The grade of phosphatic sands (feed) beneficiated by flotation methods is controlled by the concentration and grade of the phosphate particles in the feed fraction. Economics and technical feasibility limit the minimum acceptable feed grade. Ten (10) % BPL (4.58% P_2O_5) feed yields near the minimum acceptable recovery efficiencies of current extraction technology and is the lowest feed grade criteria commonly applied in evaluation of deposits.

TABLE 19. - Guidelines for determining identified
deposits for this study

1. Deposit size must be greater than 5,000,000 metric tons of recoverable phosphate rock[1] and must be within an average radius of 1.5 miles[2] from the ore body centroid.

2. Deposit size must be greater than 10,000,000 metric tons[1] if the overburden average thickness is greater than 20 feet, and must be within an average radius of 2 miles[2] of the ore body centroid.

3. Deposit size must be greater than 15,000,000 metric tons[1] if the overburden average thickness is greater than 30 feet, and must be within an average radius of 2.5 miles[2] of the ore body centroid.

4. The concentrate grade must be greater than 60% BPL (27.5% P_2O_5).

5. The flotation feed grade must be greater than 10% BPL (4.6% P_2O_5).

6. The phosphate concentration must be one ton of recoverable product per 10 yards of ore.

7. The ore zone must be greater than 5 feet thick.

8. Any product containing over 1.5% MgO will be separately classified.

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[1] Exceptions - if deposit is adjacent to larger identified deposits or is in hardrock area.

[2] This radius equates to the resource ore body covering one-half of the area of the deposit, at an average of 2,500 tons per acre.

The matrix "X", or ratio of recoverable product (dry weight) to raw ore volume, is a function of feed grade and amount, pebble grade and content, and clay content. A ten matrix "X" is related to an ore constituency of about 80% phosphate feed of 10% BPL at nominal recovery. Ten yards of ore per ton of product is equitable to approximately 800 tons per acre for a five foot ore bed. Five feet is a practical minimum thickness that can be efficiently recognized and extracted in larger scale open pit operations.

Ore with an average MgO content in excess of 1.5% was separately classified in the MAS, but included in total resources. Resolution of the MgO problem, which may be in the near future, would eliminate this designation.

The size-of-resource guidelines were applied to deposits (items 1, 2, and 3); other guidelines would be applied to prospecting areas or individual hole data.

It is important to emphasize that the parameters are used as guidelines rather than criteria - the distinction being the degree of latitude in considering exceptions. In actual practice, deposit identification was reasonably obvious and straightforward. These guidelines identified deposits or portions of an area delimitable as a deposit based on the minimum guidelines for ore concentration, and it was not usually necessary to apply size criteria. The approach was intended to be consistent for all areas of the state. When there was doubt as to classification based on physical parameters, the material was generally included (to be later classified by economic evaluation).

In areas of sparse drilling (say 1-4 holes per section), mineable area was usually determined by the percentage of mineable holes within the area as applied to the total acreage, then deleting physical or environmental restrictions (structures, streams, lakes, roads, etc.). The density of drilling, of course, determined to a large extent the probability or confidence level applied. In studying the application of economic modeling to the identified deposits, there is a correlation between cost and probability, indicating that weaker deposits were identified on more sparse data. It is assumed that this relationship could be extrapolated to some extent in expecting rejected prospecting data to be of even higher cost, but the practicality of the projection is limited by technical feasibility and data confidence.

It should be noted that environmental sensitivity was not applied as a general criteria to deposits. Resources for a deposit, however, were reduced according to the obvious environmental constraints (underlying developed land, lakes, etc.).

Summary Listing of Identified Deposits

During the course of the study, using guidelines previously discussed to evaluate deposit and prospect information gathered, phosphate was found of adequate quantity and quality to be categorized as a deposit in twenty Florida counties as shown on figure 34 with the acres underlain by identified resources described in table 20. Table 21 lists the 108 deposits identified by county and MAS designation. The deposit name in some cases has been deliberately vague in order to protect its confidentiality, as in deposits in prospect status. A deposit in geological distribution is irrespective of property boundaries. Deposits in this study may or may not cross boundaries, according to informational source and reliability.

TABLE 20. - Acres underlain by identified resources

District	Acres	Number of Deposits
Northern Florida phosphate district (includes "East Coast" and hardrock districts).............	260,171	30
Central Florida phosphate district................	135,825	38
"South Florida" phosphate district................	340,931	40
Total	736,927	108

For purpose of classification, the MAS assignment of "C" or "R" does not necessarily indicate the quality of the individual deposit, but rather the status of its development. "C" deposits are those presently being mined or acquired for mining in the foreseeable future. "R" deposits describe all other quantifiable deposits. "L" signifies deposits lacking sufficient information to quantify the resource. "C" deposits are located on figures 35 and 36.

Seventy-eight of the total deposits identified are located in the Central Florida and "South Florida" districts, with 38 in Polk and Hillsborough Counties (Central Florida district). The number of deposits identified is as much a function of the detail of information (and ownership) available as the extent of resources. The average size of deposits in northern Florida are much larger than the Central district due to lack of detailed prospecting and assignable to individual ownership.

The following discussion elaborates upon deposits listed in table 21 where appropriate and to the extent confidentiality will allow:

Alachua County

The La Crosse deposit is the only one currently owned by phosphate interests. The county has not been extensively prospected. Land ownership is dominated in the northern portion by paper companies. A very stringent mining ordinance was passed in recent years and the location of a state university in the area indicate the potential for public attitude to be somewhat negative toward mining development.

Bradford/Union Counties

The Brooker-Dukes prospect was the only one identified from available prospecting information.

Northern Florida/"East Coast" phosphate district/Hardrock phosphate district

Central Florida phosphate district

South Florida phosphate district

FIGURE 34.- Counties with identified deposits.

Key to "C" deposit maps

1. Deep Creek Deposit
2. Suwannee River Mine
3. Swift Creek Mine
4. Osceola National Forest
5. Hardrock District
6. Hardrock/Colloidal Clay
7. Brooker-Dukes
8. Big Four Mine
9. Lonesome Mine
10. Florida Agglite
11. Beker
12. Four Corners Mine
13. Duette Mine
14. Phillips DeSota-Manatee
15. Pine Level
16. Farmland
17. Acrefoot Johnson
18. Central Farmers
19. Mississippi Chemical Co.
20. IMC Horse Creek
21. Payne Creek-Palmetto
22. Fort Green
23. Saddle Creek-Ebersbach
24. Haynsworth
25. Bonny Lake
26. Hookers Prairie
27. Noralyn/Phosphoria
28. Clear Springs
29. Nichols Mine
30. South Fort Meade
31. Ft. Meade
32. Watson
33. Silver City
34. Little Payne Creek
35. Rockland Mine
36. ASMAC Minerals
37. Gardinier Fort Meade
38. Trans-Ammonia
39. Florida Phosphate Corporation
40. Kingsford
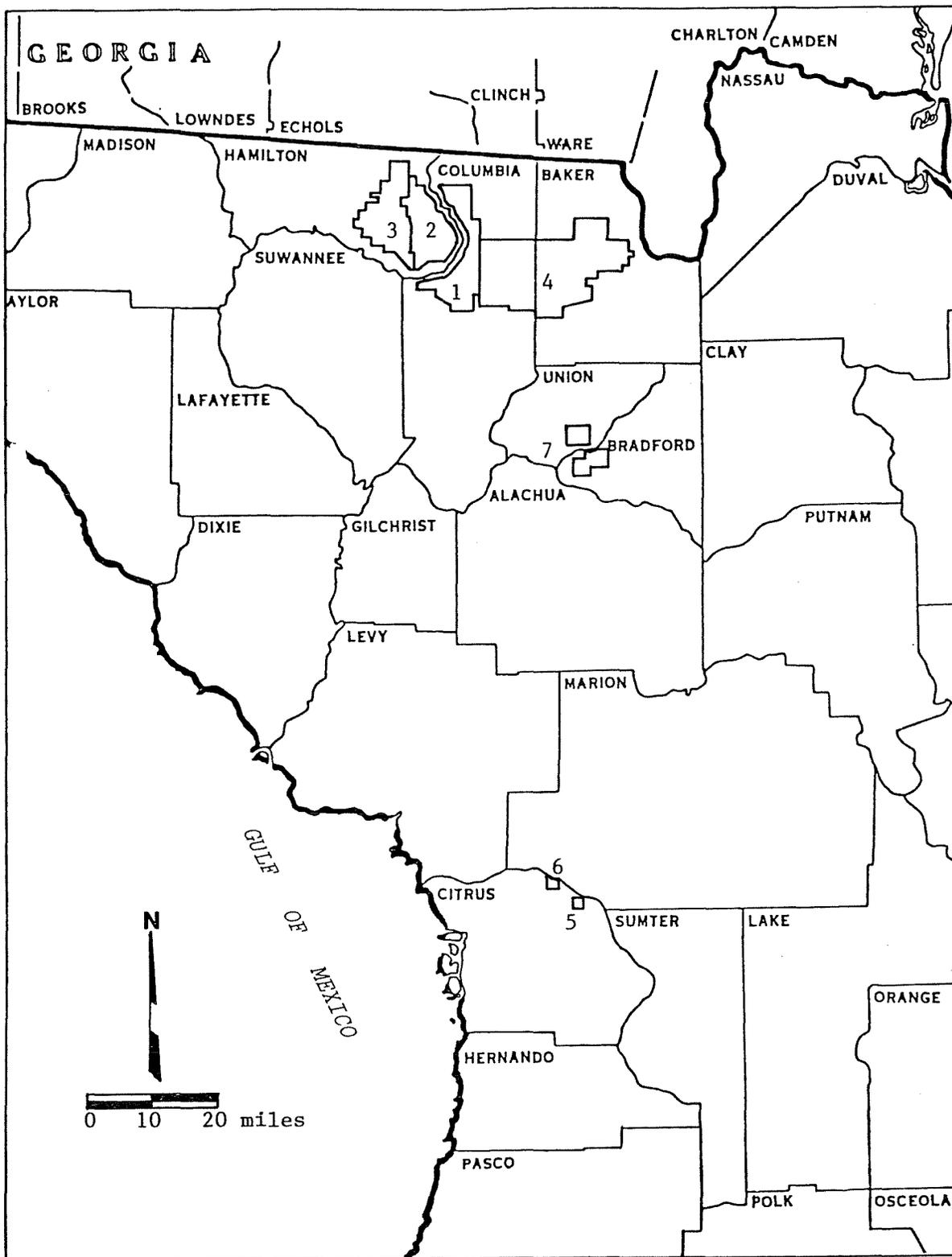
FIGURE 35. — Location of "C" deposits in Northern Florida.
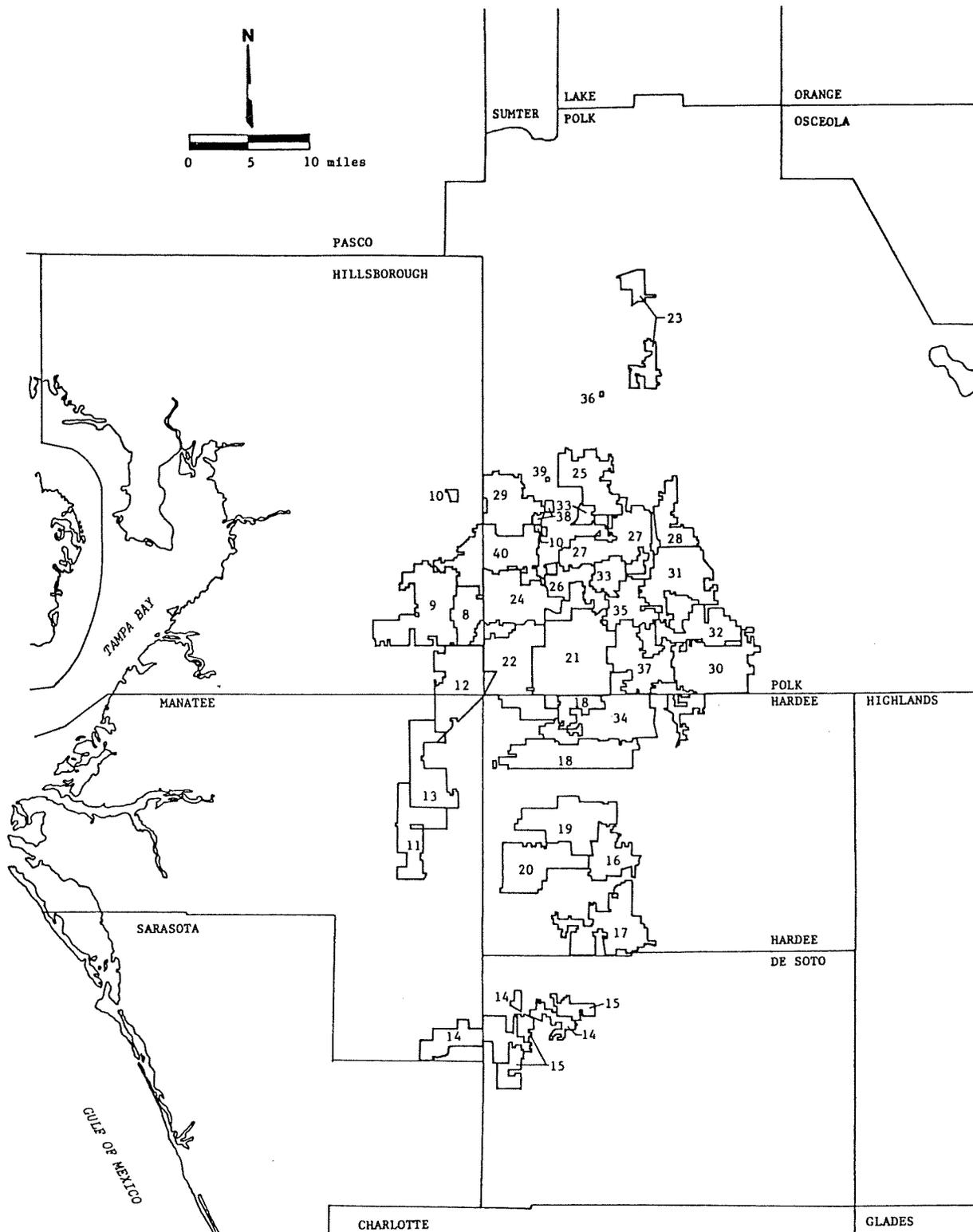
FIGURE 36. - Location of "C" deposits in Central Florida.

TABLE 21. - Identified phosphate deposits

Northern Florida phosphate district (includes Hardrock and "East Coast")

Deposit Name	Type[1]/	Classification
Alachua County		
La Crosse Deposit..........	LP	R
Lakes Deposit	LP	R
Pirkle Deposit	LP	R
Baker County		
Baker County #1............	LP	L
North Baker County Deposit.	LP	R
Bradford/Union Counties		
Brooker-Dukes..............	LP	C
Container Corporation Deposit.................	LP	L
Brevard County		
Deseret Ranch.............	LP	R
Citrus/Marion Counties		
Hardrock/Colloidal Clay...	SR	C
Hardrock Debris	DT	R
Hardrock Deposit..........	HR	C
Hardrock District.........	HR	R
Columbia County		
Columbia County #1	LP	R
Deep Creek................	LP	C
North Columbia............	LP	R
North Columbia County #2..	LP	R
North Lake City Deposit...	LP	R
Osceola National Forest...	LP	C

See footnotes at end of table.

TABLE 21. - Identified phosphate deposits - Continued

Deposit Name	Type[1]	Classification
Hamilton County		
Gary................	LP	L
Hamilton Recon......	LP	R
Suwannee River......	LP	C
Swift Creek.........	LP	C
White Springs	LP	R
LaFayette County		
Cooks Hammock #1....	HR	R
Cooks Hammock #2....	HR	R
Lake County		
Lake County Deposit.	LP	R
Saint Johns County		
St. John's County Deposit...........	LP	R
Suwannee County		
Live Oak............	LP	R
McAlpin	LP	R
Taylor County		
Eridu	LP	L

See footnotes at end of table.

TABLE 21. - <u>Identified phosphate deposits</u> - Continued

Central Florida phosphate district (includes south Florida)

Deposit Name	Type[1]/	MAS Type
DeSoto County		
DeSoto Small Owner-ships...................	LP	R
Horse Creek...............	LP	R
Phillips DeSoto Manatee................	LP	C
Pine Level...............	LP	C
Hardee County		
Acrefoot Johnson.........	LP	C
Acrefoot Johnson Small Owners.................	LP	R
Central Farmers..........	LP	C
Durrance Waters..........	LP	R
Farmland.................	LP	C
Gardinier South Hardee...	LP	R
B. H. Griffin............	LP	R
Hardee West Prospect.....	LP	R
IMC Horse Creek..........	LP	C
Limestone Land Co........	LP	R
Manson Jenkins...........	LP	R
S. Ft. Meade Small Ownerships	LP	R
Mississippi Chemical Co..	LP	C
Olliff...................	LP	R
Ona Area Small Owner-ships...................	LP	R
Sharp....................	LP	R
Town Pasture.............	LP	R
Waters...................	LP	R
Zolfo Springs Area.......	LP	R
Zolfo-Stauffer...........	LP	R
Hillsborough County		
Atlantic Richfield.......	LP	R
Big Four.................	LP	C
Boyette II...............	LP	R
East Pierce..............	LP	R
Farmland.................	LP	R
First Mississippi Chemical...............	LP	R

See footnotes at end of table.

TABLE 21. - Identified phosphate deposits - Continued

Deposit Name	Type[1]/	MAS Type

Hillsborough County

Deposit Name	Type[1]/	MAS Type
Florida Agglite........	DT	C
Hillsborough Co. Small Ownerships..........	LP	R
Hopewell Deposit.......	DT, LP	R
Hunt Brothers Ranch....	LP	R
Lithia-Boyette	LP	R
Lonesome	LP	C

Manatee County

Beker..................	LP	C
Duette.................	LP	C
Four Corners..........	LP	C
IMC....................	LP	R
Keys..................	LP	R
Manatee North Small Ownerships..........	LP	R
Manatee South Small Ownerships..........	LP	R
N. E. Manatee.........	LP	R
N. E. Manatee Small Ownerships..........	LP	R
N. E. Manatee Small Ownerships..........	LP	R
N. E. Manatee Small Ownerships..........	LP	R
Texaco.................	LP	R
Turner.................	LP	R
David C. Turner Heirs..	LP	R

Polk County

ASMAC Minerals.........	DT	C
Bonny Lake.............	LP	C
Christina Reserves.....	LP	R
Clear Springs.........	LP	C
Debris Deposits	DT	R
Florida Phosphate Corp.	DT	C
Fort Green.............	LP	C
Gardinier Fort Meade...	LP	C
Fort Meade.............	LP	C
Fridovich Deposit......	LP	R
Haynsworth.............	LP	C
Hookers Prairie........	LP	C
Kingsford.............	LP	C

See footnotes at end of table.

TABLE 21. - Identified phosphate deposits - Continued

Deposit Name	Type[1]	MAS Type
Polk County		
Little Payne Creek.......	LP	C
Nichols.................	LP	C
Noralyn/Phosphoria.......	LP	C
North Bartow.............	LP	L
Payne Creek Palmetto.....	LP	C
Pierce-Pebbledale........	LP	R
Rockland.................	LP	C
Saddle Creek- Ebersbach.............	LP	C
Silver City..............	LP	C
South Fort Meade.........	LP	C
Tenoroc Mine.............	LP	L
Trans-Ammonia	LP, DT	C
Watson..................	LP	C
Sarasota County		
Sarasota County Deposit No. 1..........	LP	R
Sarasota County Deposit No. 2..........	LP	R

[1] LP - Land pebble
    HR - Hardrock
    SR - Soft rock
    DT - Debris or tailings

Brevard County

The Deseret Ranch prospect as recently announced covers 20,000 acres in the southwestern part of the county. A similar deposit was located in St. Johns County, and they comprise the only two identified areas along the Florida east coast.

Columbia County

This county and neighboring Hamilton County comprise the heart of the northern Florida district in terms of substantial identified resources. Occidental's Deep Creek prospect on the northwestern boundary covers a number of individual ownerships.

The Osceola National Forest deposit actually includes some portions of western Baker County. The prospecting lease rights are commonly held by four companies; Global Exploration, Kerr-McGee, Monsanto Chemical Company, and Pittsburgh-Midway Coal Company. The deposit information and resource establishment was more readily presented in this case by grouping their interest with the government-held lands in the forest, and a few small ownerships.

Citrus, Lafayette, and Marion Counties

Deposits in the Hardrock district were difficult to assign because of proliferating housing development and other land activity in the Marion/ Citrus County area, the small deposit size of most hardrock occurrences, and the by-product or tailings resources available and being mined. Hardrock deposits were grouped as follows:

- The former TVA holdings and deposits in their proximity were grouped into the "Hardrock District" deposit of Citrus/Marion Counties.

- Individually owned or identified prospects in the area controlled by mineral interests were separately quantified in Citrus, Marion, and Lafayette Counties.

- Colloidal clay debris "softrock" is scattered throughout the area in small patches. The four present mining operations are very competitive and individual ownership information is scanty; therefore, these deposits and operations were grouped and evaluated as a single deposit - "Hardrock/Colloidal Clay".

- Hardrock "debris" represents "screenrock" or sand-sized debris from previous mining operations. It has distinctly different characteristics and development potential from either the softrock or hardrock and was separately lumped as "hardrock debris".

Polk County

All deposits listed are owned by mining companies with the exception of
"debris" or tailings deposits. A portion of the debris and tailings were
assigned to ASMAC Minerals, Florida Agglite, and Florida Phosphate Corporation
plants, since these deposits were identified by the companies as under their
control. The remaining debris and tailings deposits identified but not under
the ownership of mining companies were grouped as a single "debris" deposit.
This resource is known to be presently available to scavenger or other opera-
tors. Tenoroc Mine is presently processing some debris from Borden's abandoned
operations in Hillsborough County, although the ore at the site has been
depleted. Impounded colloidal clays of Polk and Hillsborough Counties were not
treated as an identified deposit. Until their extent, viability for future
P_2O_5 extraction, and cost are further established, they cannot be identified as
deposits. They are and should be categorized, however, as a resource.

DeSoto, Hardee, and Manatee Counties

These counties comprise the South Florida district and have been the
center of most prospecting and mine development activity in the past five
years. A great deal of both older and recent resource information was avail-
able. A number of small ownerships were identified singly or, if very small,
logically grouped in these counties. The mineable portion of these ownerships
are likely to be mined when mining progresses southward in the coming decades.
They will in some cases probably be purchased by adjacent large mineral owner-
ships, or in a few cases are likely to be combined into a newly identified
development.

Summary

The deposits as listed within this section of the report represent a
comprehensive listing of deposits presently identified in Florida. It is not
complete in that a number of deposits may be omitted due to inaccessibility of
information. Based upon the cooperation of many parties and the authors'
experience in the area, however, the potential omission of presently identified
deposits is not believed significant. The potential for expansion of the
state's resources in the future is discussed in the following section.

CHARACTERIZATION OF IDENTIFIED RESOURCES

In this section, the deposits previously identified are categorized and quantified by two districts: (1) the Central Florida phosphate district includes the "South Florida" district and represents all land-pebble phosphate in DeSoto, Hardee, Hillsborough, Manatee, Polk and Sarasota Counties; (2) the Northern Florida phosphate district resources include marine sedimentary phosphorites of counties previously listed in the district in table 21, plus the Hardrock district and the two identified deposits in the "East Coast" district. This combination is necessary for the purpose of preservation of confidentiality for individual deposits. Table 22 lists the resources in terms of cost and grade for each district for recoverable product. They are further broken out in this presentation individually for Polk, Hillsborough and Hardee Counties, which contain a sufficient number of deposits to retain listing. "C" and "R" deposits are combined and represent the total resources identified in the study. In table 24, the "R" deposits are summarized separately to show the combined "R" resources in place and in tons of recoverable ore at various levels of probability. The probability is additive; that is, 75% probability resources include 90%, 50% probability include 75% and 90%, etc. Probability is determined primarily by the validity of the data in terms of detail and source. Lower probability indicates lower confidence in the resource. Also listed on tables are the total estimated product recovery of in situ phosphate product, which is the factor used to derive recoverable ore from ore in the ground (see table 25). "Recoverable ore" is a back calculation of recoverable product times ratio of concentration, and does not represent mine recovery alone. This calculation is necessary to represent resources in terms of ore tons for the MAS system. The P_2O_5 of the ore is that recoverable as product, and not the total "head" content.

Table 23 lists in a similar fashion as table 24 the "C" deposits, and in addition lists other estimated by-product commodity content, including gangue P_2O_5 content, F, U_3O_8, Fe_2O_3, Al_2O_3, and MgO.

The "P_2O_5 gangue" added to the "P_2O_5 ore" column should equal total ore P_2O_5 or "head" content. The gangue P_2O_5 content, however, is less reliable in that specific data on waste P_2O_5 was not usually available; therefore the value is the product of a calculation of the weighted content of waste products (waste pebble, tailings, and clay) and their given, calculated, or estimated P_2O_5, depending on the extent of data offered or available. The ore gangue contents shown are therefore to be considered the summary of reliable estimates and not of specific data.

The ore content of the remaining commodities listed are, as in the manner of P_2O_5, back calculations of their content in the separated rock product divided by the ore ratio of concentration. In the case of uranium, little deposit-specific data was made available to the study. The few average U_3O_8 contents for deposits which were offered have been entered into the program. For the remainder, an assignment of product uranium content was made according to district. A survey of pertinent literature and in-house information indicates that each of the districts has a typical (but not uniform) content based on the geological-metallurgical character of the district. It has been acknowledged that the uranium content is related to the grain size (the pebble being more uraniferous than concentrate), age of reworked ore (Bone Valley being higher than the Hawthorn), and the P_2O_5 content (uranium

TABLE 22. - Total identified resources in recoverable
product tons by grade and cost

| Location | Million short tons | | | | | | | Total millions. tons | Product grade BPL |
| | Cost $/short ton of product | | | | | | | | |
	<15	15-20	20-25	25-30	30-35	35-40	>40		
Northern Florida....	4.35	308.86	617.97	317.56	127.07	14.00	8.00	1397.81	66.4
Central Florida									
Polk County.......	374.00	309.78	-	0.20	9.80	1.53	-	695.31	68.9
Hillsborough Co...	50.00	30.00	94.90	9.63	8.00	-	2.00	194.53	71.4
Sub-Total I....	424.00	339.78	94.90	9.83	17.80	1.53	2.00	889.84	69.4
South Florida									
DeSoto, Manatee and Sarasota Counties..........	-	448.40	179.60	236.00	60.00	77.20	-	1001.20	66.1
Hardee County.....	-	287.00	185.00	202.50	81.45	24.00	81.00	860.95	66.2
Sub-Total II...	-	735.40	364.60	438.50	141.45	101.20	81.00	1862.15	66.1
Total I + II...	424.00	1075.18	459.50	448.33	159.25	102.73	83.00	2751.99	67.2
Total Florida......	428.35	1384.04	1077.47	765.89	286.32	116.73	91.00	4149.80	66.9

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TABLE 23. – Identified resources ("C" only), total tons of in place ore, recoverable at various probabilities, and commodity content

Location	Million short tons ore in place	Probability (million short tons recoverable ore)				Weighted average % in ore						
		90%	75%	50%	25%	P_2O_5 Ore[1]	P_2O_5 Gangue	F	U_3O_8	Fe_2O_3	Al_2O_3	MgO
Northern Florida includes Hardrock	2370.30	–	767.59	1151.84	1709.84	5.24	3.34	0.50	0.0013	0.21	0.18	0.096
Central Florida												
Polk County	3249.80	1290.61	2288.55	2588.20	2641.47	7.93	4.27	0.87	0.0038	0.34	0.30	0.13
Hillsborough County	364.21	291.36	291.36	307.81	307.81	8.87	2.75	1.03	0.0041	0.34	0.31	0.13
Sub-Total	3614.01	1581.97	2579.91	2896.02	2949.28	8.03	4.11	0.89	0.0038	0.34	0.30	0.13
South Florida												
Hardee County	3887.30	1285.47	1963.33	2540.71	2883.11	4.89	3.06	0.51	0.0014	0.23	0.20	0.15
DeSoto, Manatee, and Sarasota Counties	2221.94	648.60	1553.97	1794.59	1794.59	5.96	2.51	0.64	0.0011	0.26	0.25	0.12
Sub-Total	6109.24	1934.07	3517.30	4335.30	4677.70	5.30	2.85	0.56	0.0013	0.24	0.22	0.14
Total Florida "C"	12,093.55	3516.04	6864.80	8383.16	9360.20	6.14	3.34	0.65	0.0021	0.27	0.24	0.13

[1] P_2O_5 content of ore is not head sample, but that calculated as recoverable from ore at 25% probability. (See paragraph 3 under Characterization of identified resources.)

TABLE 24. - Identified resources ("R" only), total tons of in place ore,
recoverable at various probabilities, with P_2O_5 content

Location	Million short tons ore in place	Probability (million short tons recoverable ore)				Weighted average % P_2O_5 in ore[1]
		90%	75%	50%	<25%	
Northern Florida (includes Hardrock).	9,211.04	-	-	228.73	6019.89	5.52
Central Florida						
Polk County........	218.54	-	156.41	165.53	165.51	6.56
Hillsborough County.	804.52	61.43	371.05	460.03	564.45	6.43
Sub-Total (Central).	1,023.06	61.43	527.46	625.56	706.58	6.46
South Florida						
Hardee County.......	3,636.42	-	1056.31	2161.71	2584.78	4.68
DeSoto, Manatee, and Sarasota Counties	7,088.77	-	2085.94	3868.22	4717.99	4.16
Sub-Total (South)...	10,725.19	-	3142.25	6029.93	7302.77	4.34
Total Florida "R".....	20,959.29	61.43	3669.71	6884.22	14029.24	4.95

[1] P_2O_5 content of ore is not head sample, but that calculated as recoverable from ore at 25% probability.
(see paragraph 3 under Characterization of identified resources.)

TABLE 25. — <u>Total identified resources ("C" and "R")</u>
<u>of in place ore tons and grade</u>

Location		Million short tons ore in place	Weighted average % P_2O_5 in ore
Northern Florida	C	2,370.30	5.24
Includes Hard Rock......	R	9,211.04	5.52
North Florida District Sub-total............		11,581.34	5.46
Central Florida	C	3,249.80	7.93
Polk County.............	R	218.54	6.56
Sub-total Polk........		3,468.34	7.84
Central Florida	C	364.21	8.87
Hillsborough County.....	R	804.52	6.43
Sub-total Hillsborough		1,168.73	7.19
Central Florida District Sub-Total...		4,637.07	7.68
South Florida	C	3,887.30	4.89
Hardee County	R	3,636.42	4.68
Sub-total Hardee......		7,523.72	4.79
South Florida	C	2,221.94	5.96
Manatee, Sarasota, DeSoto.................	R	7,088.77	4.16
Sub-total.............		9,310.71	4.59
South Florida District Sub-Total............		16,834.43	4.68
Total Florida.........		33,052.84	5.37

NOTE.--P_2O_5 content of ore is not head sample, but that calculated as
recoverable from ore. (See paragraph 3 under <u>Characterization of identified</u>
<u>resources</u>.)

increases with P$_2$O$_5$ content) in marine phosphorites. With sufficient data, these relationships can be demonstrated. The data base available, however, is insufficient to establish such a graphical relationship to that specific deposit. Uranium content can be derived based on the variables previously mentioned. Therefore, a standard uranium content was assigned to each "C" deposit within a district based on the district's overall metallurgical characteristics and supporting analytical data as below:

District	Uranium content (ppm)
Central Florida	120
"South Florida"	90
Northern Florida	80
Hardrock	100

MgO content increases with downdip geologic position (increasing carbonates) and is mapped on figure 12. There is insufficient distribution in the data to similarly map F, Fe$_2$O$_3$, or Al$_2$O$_3$ on a regional or statewide basis. There is an observed relationship, however, between higher MgO content and correspondingly reduced Fe$_2$O$_3$ and Al$_2$O$_3$.

Economic Classification

Classification of reserves is the prime function of the MAS. Reserves are classified through geologic, engineering, and economic evaluation of identified resources. A reserve is classified by determining resource availability at a specified price. Availability is a function of resource delineation, mining and metallurgical feasibility, and extraction costs.

Table 22 indicates the total identified resources in recoverable product tons by grade and cost available for mining extraction under acceptable conditions. Environmental and certain technological considerations are to some extent subjective and can change with time. Economics or cost data, however, are most objective in relating and delineating reserves from total resources, although costs can suffer abrupt changes upward in such non-controllable areas as taxing or regulatory matters, or downward in technologic achievements in production efficiency or recovery.

On table 22, that portion of the total resource to be identified as reserves is dependent on the current cost/price relationship. As of mid-1978 writing, the average price of phosphate rock is near $16.00 per short ton as compared to an average production cost of approximately $13.00. Therefore, the current "reserve" portion of table 22 is the identified reserves in the $\leq$$15.00/ton column and some portion of the adjoining $\leq$$20.00/ton column.

Rejecting inflationary or escalatory increases in such areas as power, labor, etc., the cost of mining and beneficiating deposits can be established and projected. A previous section described costing and cost modeling techniques applied to each of the identified "C" or "R" deposits. These costs assigned to each deposit are the basis for the total resource evaluation in terms of availability at various constant dollar cost levels. It is assumed that the market in terms of both the domestic and world supply-demand relationships will dictate the future price and demand, thereby establishing acceptable production cost limits.

Central Florida District

Figure 37 shows the relationship of total resources in the Central Florida district to estimated production cost (the Central Florida district in all graphs includes "South Florida" deposits). Note the units are constant 1977 dollars per dry short ton. The tons in these and following graphs are expressed in short tons of recoverable product, which is the more familiar term in the industry. MAS encodement, however, expressed the ore in dry metric tons. The spread of costs are the sum of the various matrices for all deposits; that is, a single deposit may be divided into several cost increments based on different ore qualities within the deposit. The logic is
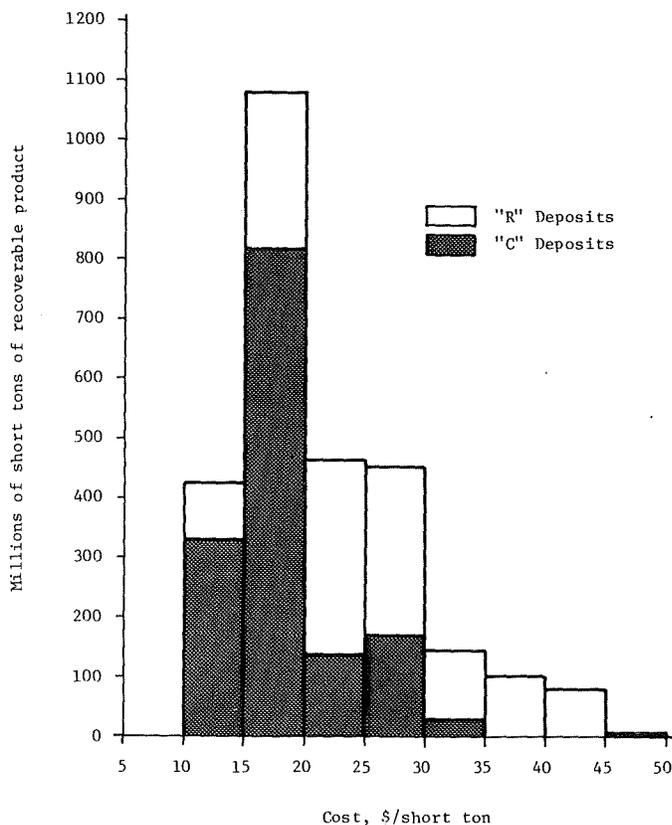
FIGURE 37. - Central Florida district: product tons versus cost.

that the producer will operate on that quality ore that represents accept-
able costs under the prevailing economic climate. Thus in Florida phosphate
deposits, phosphorite may be relegated to "reserve" or "resource" status
depending on the production cost versus market price relationship.

New deposits will not be developed until there is adequate cause for the
developer to believe his deposit contains sufficient recoverable reserves to
amortize the capital investment and provide an acceptable return on investment.
The graph in figure 37 illustrates that $2.00-$5.00 changes in rock prices can
and do have significant impact on the classification of identified resources
into or out of reserve categorization. Only about 424,000,000 tons are
presently available at less than $15.00/ton (slightly below current average
sales prices). However, an additional 1,075,000,000 are available at a $5.00
increase in the Central and South Florida districts.
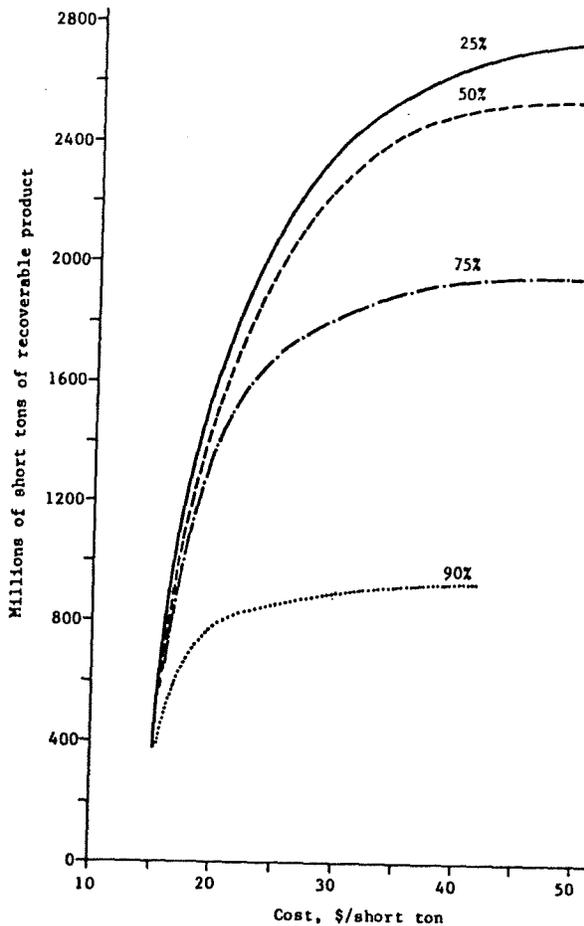
FIGURE 38. - Probability levels of resources - Central Florida district.

Resource identification in the Central Florida district is extensive, and the total resource is not expected to substantially increase without technological breakthroughs in such areas as recovery of P_2O_5 from slimes, beneficiation and recovery of P_2O_5 from Hawthorn limestone underlying the region, reduction of losses, etc. Central Florida waste and Hawthorn resources will most likely be relegated to distant future resources in view of the availability of resources in the near present cost range. Technical improvements can extend onging operation reserves but reprocessing wastes were included in the study.

Figure 38 shows the previous graph in terms of confidence of resources estimation (probability) as a function of cost. It shows a superior level of confidence (75%) for most identified resources, and adequate (50%) for most of the remainder. Fifty percent or better confidence levels by study definition required review of some data for the deposit; thus the small amount attributable to inference is obvious.

<center>Northern Florida District</center>

A similar presentation of the resource-cost relationship is shown for the Northern Florida district in figure 39 (the Northern Florida district in all graphs includes Hardrock and the "East Coast" districts). The difference in identified resource magnitude of both "R" and "C" deposits, as well as the median cost increase is striking. Note, however, that the identified resources in the $20.00-25.00 range exceed Central Florida. The <$10.00 costs are
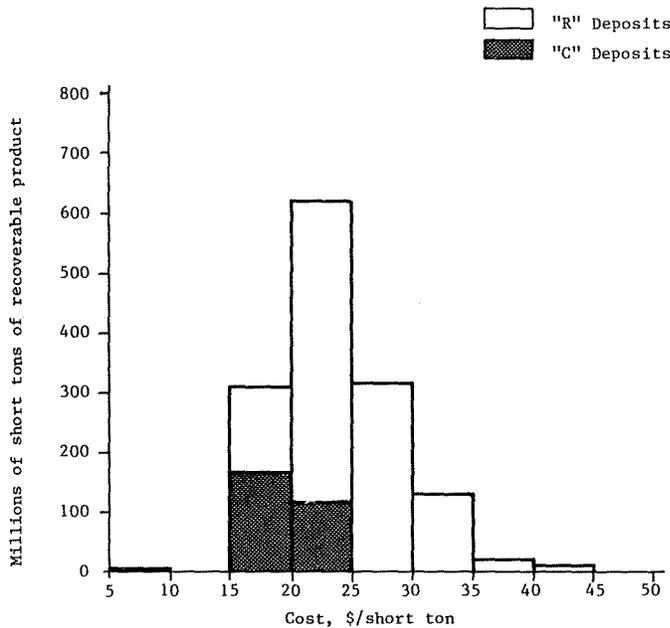
FIGURE 39. - Northern Florida district: product tons versus cost.

those assigned to colloidal clay operations. No other deposits are identified at less than $15.00 production cost, but almost one billion are available at a $10.00 increase. The prospect for additional resources identification is good, although it is not expected that such discoveries will include higher quality (and lower cost production) ore than presently identified. More important to the establishment of resources is the additional data collection necessary to improve probability. Figure 40 shows that, in sharp contrast to Central Florida, only about 225,000,000 tons is of 50% or greater confidence. The wide gap between that level and the 25% represents deposits identified and
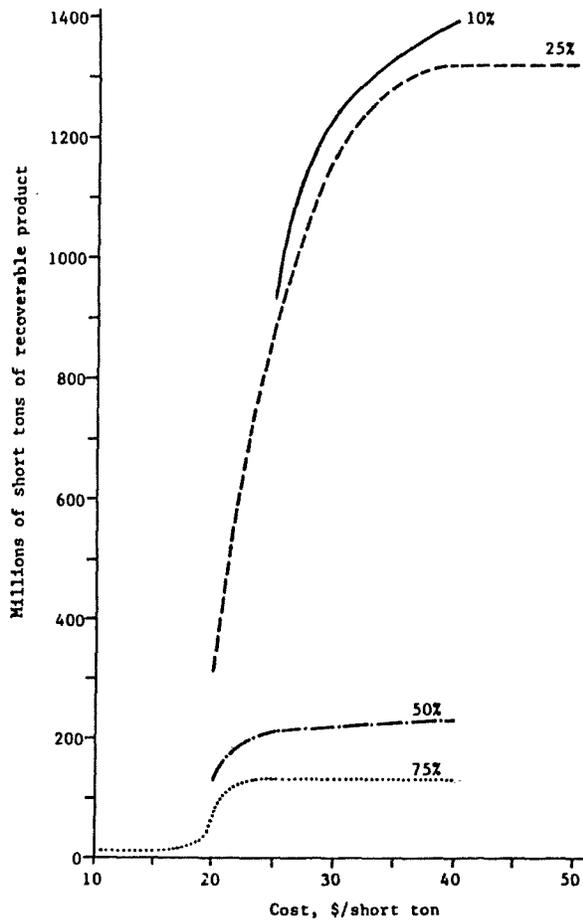
FIGURE 40. - Probability levels of resources - Northern Florida district.

qualified on a low density of prospecting (as low as one hole per section). It is expected that higher drill density would produce a similar total resource estimate, but that the number of deposits would substantially increase. Lack of infrastructure in some areas could delay mining and other contingencies could establish mine development prioritization. It is not expected that such high density drilling will be accomplished on a regional scale such as in Hardee-Manatee-DeSoto Counties for some period of time, with the exception of "C" deposits and local immediately adjacent areas. It is expected, however, that a great deal of this land will remain available for some time into the future due to predominant ownership by large companies that are presently utilizing the land for forestry products. There are, of course, some exceptions.
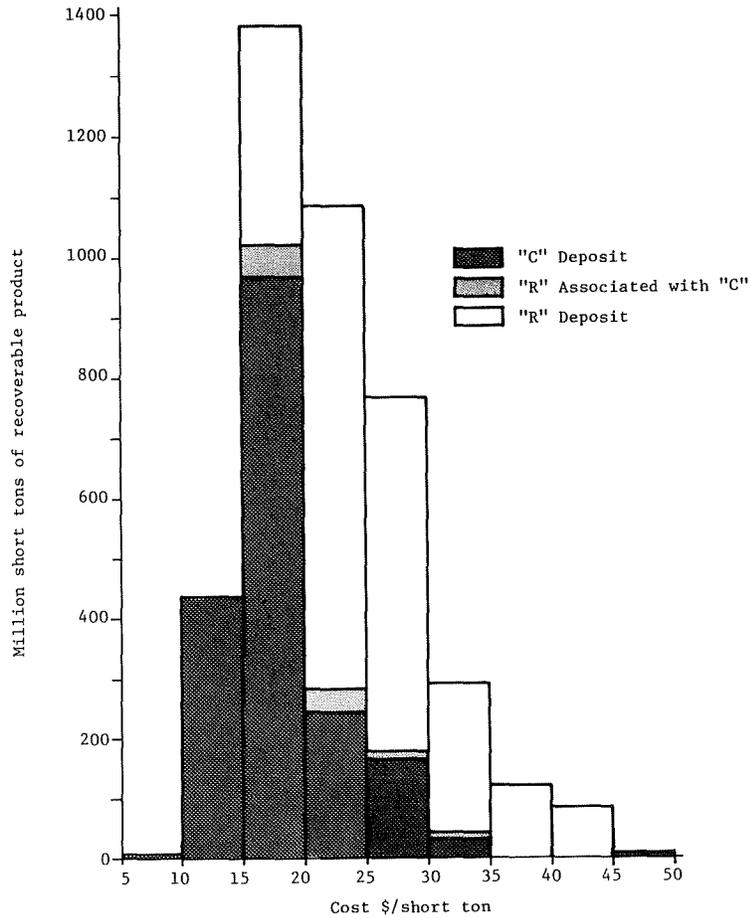
FIGURE 41. - Total resources, combined Northern and Central Florida districts.

Combined Districts (Total Florida)

Combining of the resources of the two districts into statewide representation is shown in figure 41. In this figure those "R" deposits contiguous to existing "C" deposit producers that are likely to be recovered by that plant are separately identified. The total recoverable product tons at less than $15.00 is limited, but at less than $20.00 is about 1.8 billion tons. Tables 23 and 24 illustrated that probability decreases as cost increases, indicating that lower cost resources, say <$25.00, are much better identified than higher cost resources. The combined probability of total identified resources in Florida is shown in figure 42.
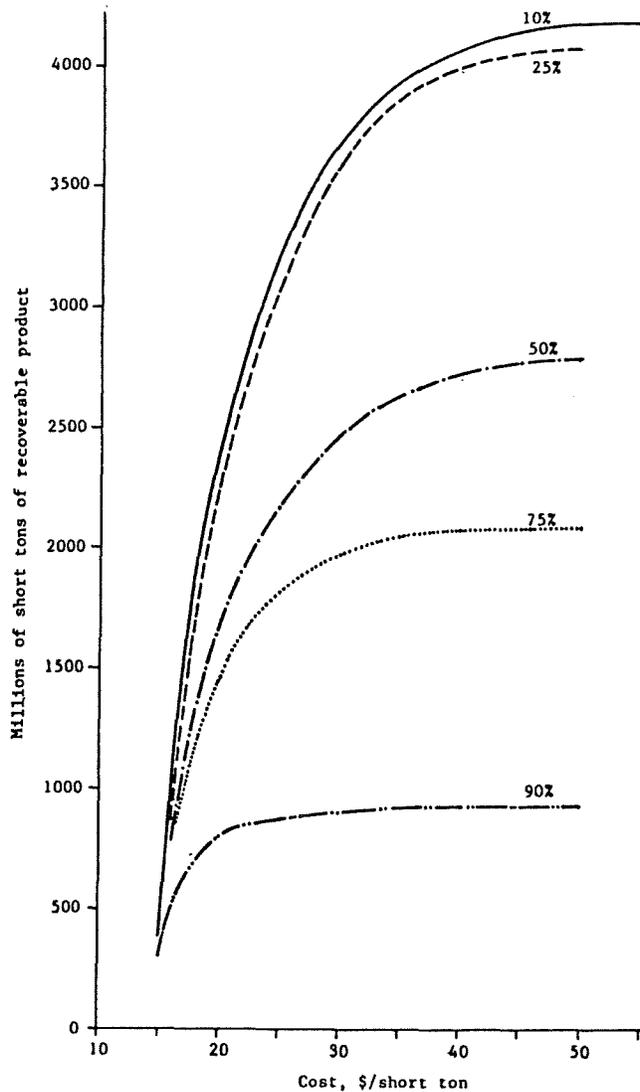
FIGURE 42. - Probability levels of resources - combined Northern and Central Florida districts.

Of the "C" deposits shown in figure 43, the cost experience of existing producers relative to that projected for new development is shown. Please note again that the graph represents distribution of the various quality ores within single deposits as well as total deposit costs. The existing producer cost is shown to be obviously lower than projected (Cases I-III versus Cases IV and V) due to lower depreciation and higher quality rock. The distinct advantage of pebble as a substantial portion of the total product is also a factor. This factor, which is only part of the total cost advantage, is seen in figure 44, which is a plot of the relationship for the identified "C" deposits.
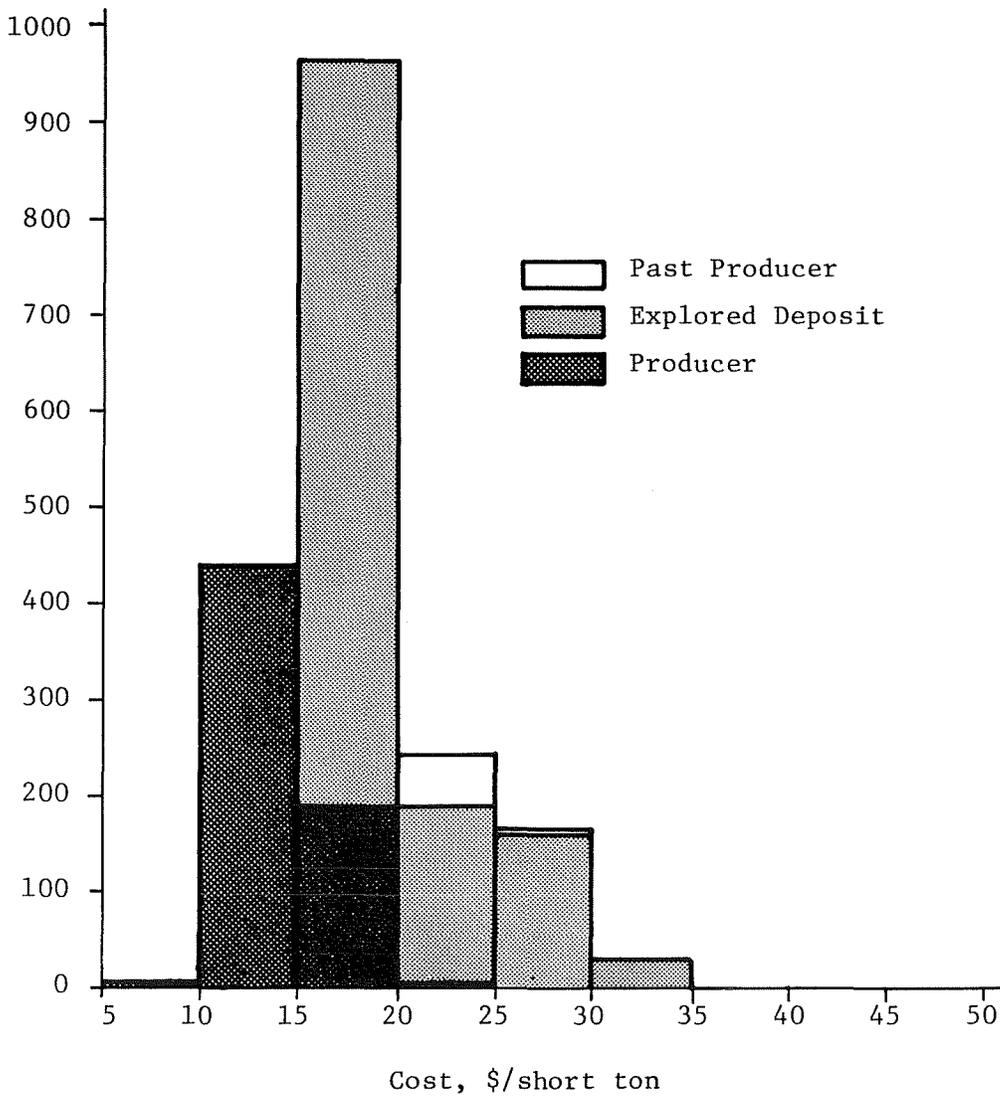
FIGURE 43. - "C" deposits only, combined Northern and Central Florida districts.

The previous cost/resource discussion is for the purpose of establishing availability of resources under competitive markets by private producers. It can be assumed that Florida will exploit its resources to the extent that they are competitive with other domestic or world markets. The projection of Florida's ability to meet a continuous growth from the present level of demand based on presently identified resources is discussed in the production capacity section of this report, page 162.

In reviewing the graphs, large resource quantities at "similar" costs become apparent. This is possibly misleading for the present, because in the keen competition of today's market production costs are significant to the $1.00-2.00 range in determining economic viability. The recent decline in phosphate prices has caused industry austerity, particularly those in a marginal cost position, and has in fact closed several small, higher cost plants. The financial advantage of internal consumer (acid producer) notwithstanding, mines will be developed in a cautious economic manner with priority going to incrementally lower cost (higher quality ore) production.
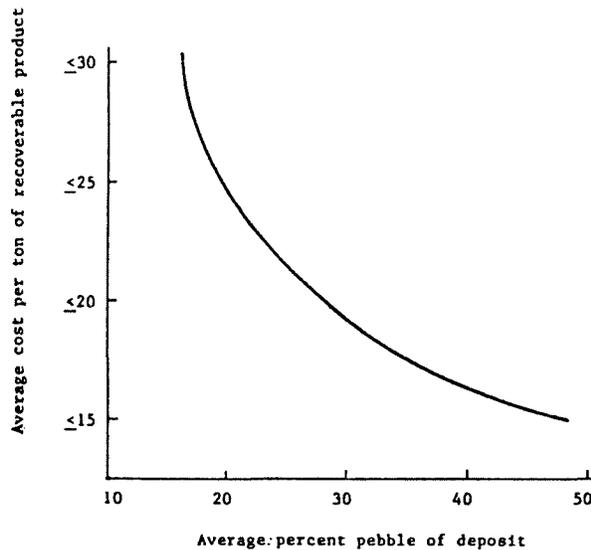
FIGURE 44. - Percent pebble versus cost of "C" deposit production.

Grade Classification

In 1976 and 1977, Florida (including North Carolina) produced an average grade phosphate rock product of about 67.9% BPL (31.1% P_2O_5). This grade production represents a continuation of a slow decline in phosphate grade in the past twenty years as higher grade deposits in the Central Florida district are being depleted. Of this production, exports are usually of higher grade (average 32.1% P_2O_5 in 1977)[25]/ rock due to premium prices and the economics

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[25]/ U. S. Bureau of Mines. Phosphate Rock 1977. Advance Summary, March 15, 1978, p. 5.

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of shipping higher grades overseas. Domestic fertilizer producers accommodate lower grade rock products (31.0% P_2O_5 in 1977) to take advantage of the lower price, and most phosphoric acid plants are constructed to operate on lower grade material.

Figure 45 graphs the resources of the Central Florida district in terms of grade and associated costs. It is important to re-emphasize that land pebble deposits are heterogeneous, and the graph of total resources represents the compilation of the average grade for each deposit. The major portion of resources lies within 66-70% BPL (30-32% P_2O_5); and the lower costs are related to higher grade product, reflecting the remaining reserves in the richer areas of the Central Florida district.
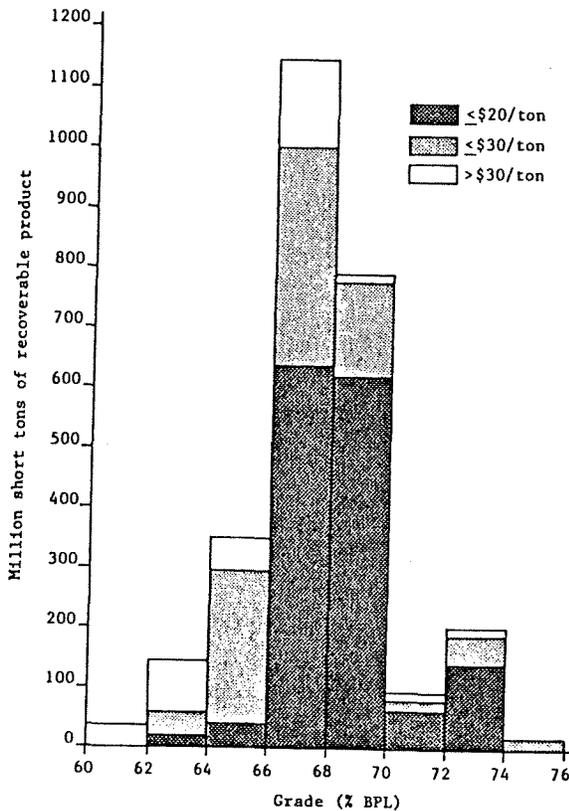
FIGURE 45. - Central Florida district: product tons versus grade (% BPL).

Figure 46 is a similar representation for the Northern Florida district as previously defined. The association of lower costs and higher grade is even more apparent than in central Florida. Equally important is the lower distribution of product grade.
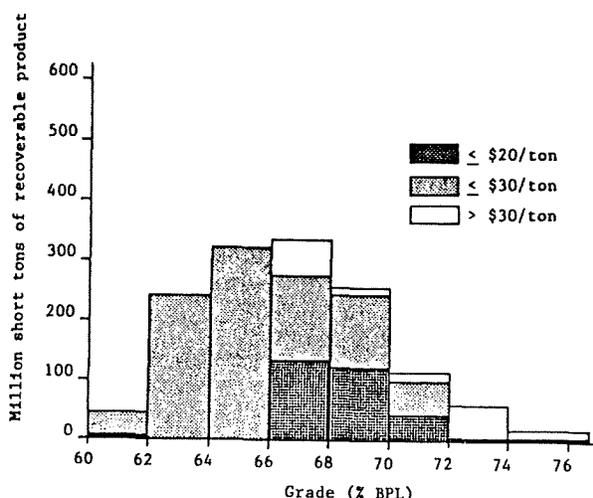
FIGURE 46. – Northern Florida district:
product tons versus grade (% BPL).

The combined grade distribution of Florida resources is drawn in figure 47, and serves to emphasize the relationships and distribution previously discussed. The lower cost for higher grade rock is not a result of higher grade rock being more cheaply produced, but of the cost and rock quality both being related to ore quality. This relationship is shown in figure 48 which is a plot of "C" deposits only, with producing deposits identified. The grade distinction would be even more pronounced if not for the pebble content of presently exploited deposits, which tends to lower average product grade. New "C" deposits will have predominantly a concentrate product, and thus will be able to sustain the average grade being presently produced.

The fact that the higher average grade deposits are those being presently exploited is generally observed in figure 48 and is significant in the fact that rock exports are grade sensitive. The resource product grades outlined above are those produced by standard beneficiation techniques. It is possible to increase these to a variable extent by further beneficiation (at P_2O_5 loss) or calcining (higher energy cost).

The effect of product contaminants on the resource availability is not presently quantifiable. Iron and aluminum content are not believed to be constraints, except possibly for a few hardrock deposits, if used as acid plant feed. Free organics requiring calcination have not been recognized in most Florida deposits. Magnesium is not potentially a constraint, as most present phosphoric acid plants are not designed to accept phosphate rock of average MgO content in excess of about 0.6%. There is some existing phosphoric acid technology to improve this tolerance, but the cost of plant
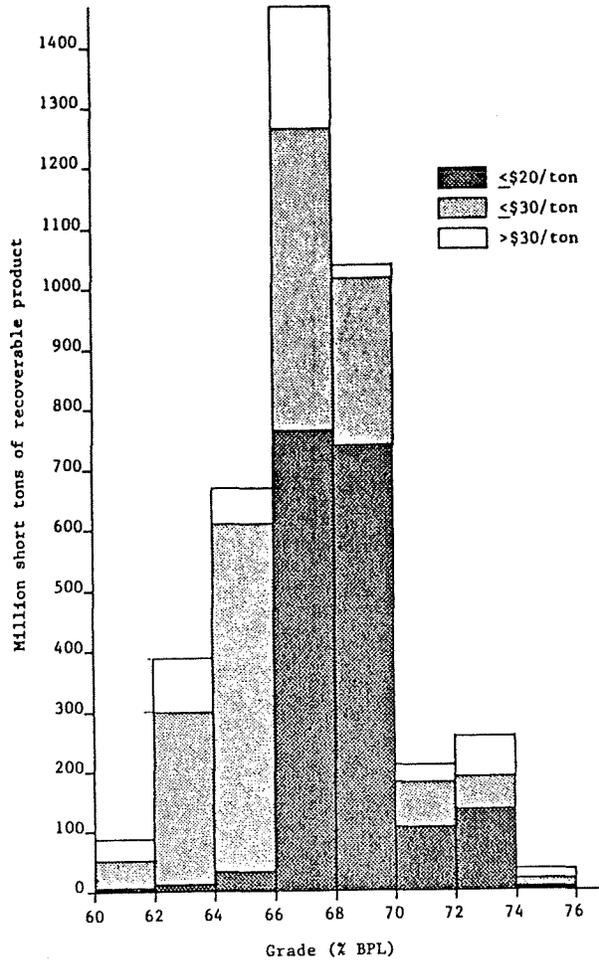
FIGURE 47. – Combined Northern and Central Florida districts:
product tons versus grade (% BPL).

adaption and a maximum increased level have not been, at least publicly,
established. Several acid producers are presently studying the problem, and
it is generally believed the ability to accept higher MgO levels will be
linked to correspondingly lower iron and aluminum in the feed and possibly
the production of more lower analysis fertilizer chemicals such as mono-
ammonium phosphate (MAP). The technology of impurity precipitate removal
from phosphoric acid is also expected to improve or offset the detrimental
effects of high MgO rock.

The higher magnesium content is generally associated with lower grade
product and, in particular, concentrates below approximately 67% BPL, which
is usually linked to more downdip, calcareous or dolomitic phosphoritic
strata. In addition to phosphoric acid process modifications, the distinct
possibility exists for effective rejection of MgO occurring as free dolomite
during the beneficiation process (flotation). This has been demonstrated on
a bench scale, and one operating company has prepared a patentable flowsheet

Post Producer
Explored Deposit
Producer
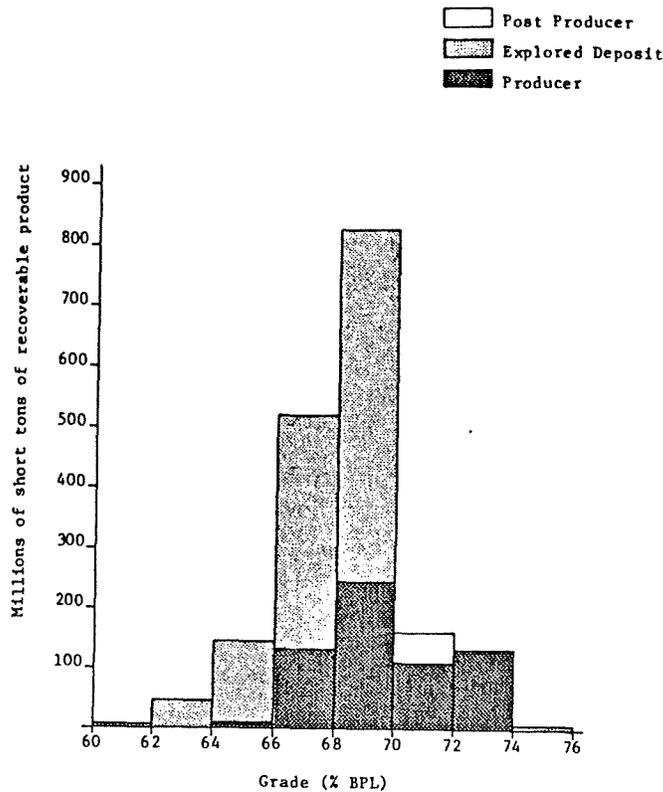
FIGURE 48. - "C" deposits, combined Northern and Central Florida districts:
product tons versus grade (% BPL).

(pending) for rejection by selective flotation. On the basis of past testing,
it appears that the "locked" MgO (that is, chemically substituted) does not
usually exceed levels of 0.5-0.7%. Thus, the prospect for product beneficia-
tion at a level presently acceptable to phosphoric acid producers depends on
the efficiency of free dolomitic rejection with tolerable P_2O_5 loss.

The lower grade products also contain more CaO, which increases
phosphoric acid production costs due to a higher consumption of sulfuric acid.
Generally, the excess calcium can be processed satisfactorily; however, the
economic incentives for improved rejection of dolomitic - calcareous minerals
in the beneficiation process are great.

In summary, beneficiation and/or acid plant process modifications may be
necessary to accept lower grade rock product inclusive of higher MgO from
some identified deposits. The prospect for the accomplishment of this is
reasonable but, of course, is based on economic incentive, which will not be
provided until after at least some depletion of higher quality available
resources.

Environmental Classification

In recent years, the environmental aspects of strip mining for phosphate in Florida have received broad exposure. The industry presently mines at the rate of about 2,000 hectares (4,940 acres) per year.[26]

26/ U. S. Environmental Protection Agency. Areawide Environmental Impact Statement (Draft), Central Florida Phosphate Industry, March 1978, 201 pp.

The cumulative effect of this mining rate on the area's resources and land displacement has been one of growing public and governmental awareness and concern in the past decade. Development activities in locating and permitting deposits south of Polk and Hillsborough Counties have been carried out at an unprecedented level since 1974 as companies moved quickly to acquire future reserves. These were acquired by operating companies to replace those being depleted in Central Florida, or by phosphoric acid producers (such as farmer cooperatives) who had experienced a price squeeze in 1974-75 and as a result decided to acquire a basic mineral position. This high level of property acquisition and permitting proceeded to cause some trepidation by the public as to the possible impact - in some cases considered devastating - that this apparent proliferation of strip mining might cause on the area's resources and economy. Through lack of credible testimony or definition of what such combined impact might be, public concern continued to grow, particularly in the area of water resources, radiation, and wetlands disturbance. Mitigation of these effects for the long term brought attention to current reclamation practices and the question of eventual disposition of almost 100,000 acres of derelict lands mined prior to 1975 when reclamation became mandatory.

Adding to the sensitivity, is the resistance to this apparent "onrush" of mining into DeSoto, Hardee, and Manatee Counties was the concern by those dependent on the area's present economic base. Although identified mineral development areas lie within an area devoted almost entirely to agricultural uses, the developments (particularly in Hillsborough and Manatee Counties) are sufficiently close to coastal areas with a tourism-retirement economic orientation to cause wide consternation to those communities. The basic issues have evolved as to the ability of each region to support industry demand on natural resources and the public's willingness to abide industrial strip mining development. Although Florida has led world production of phosphate for over seventy years, the public image of the state is in startling contrast.

The result of this conflict has been rapidly growing regulation by various levels of government discussed in another section of this report, increasing public involvement in the development and permitting process, and mitigative technologic innovation in reclamation and water management by the pressured industry.

It is thus very appropriate to evaluate the resource potential of the state from an "environmental sensitivity" point of view. The MAS provides for such input on a deposit by deposit basis, with a numerical assignment of "sensitivity" in the areas of land, vegetation, wildlife, water, air, aesthetics, sound, and "overall" in terms of both short and long

term effects.   Short term is defined by MAS as the period of mining, and long term that period following reclamation.

It is important to recognize that the System measures "sensitivity" or "people's reaction" rather than actually identifiable functional impact; that is, the actual impact may be more or less than the concern of citizens. This approach is valid in that the concern rather than the actual impact will determine the ability to mine and recover the phosphate resource.   It does impose two difficulties, however, which weigh on the credibility of evaluation: (1) the evaluation is subjective, and Zellars-Williams, Inc. had no basic guidelines for numerical assignment, and (2) "sensitivity" or people's reaction is temporal, and topical "sensitivity" may rise or fall according to future public opinion, establishment of credible mitigative action, or technological advances.

The system allows the coding in a numerical basis of 0 - 6 as follows:

0 - Undetermined	4 - Significant
1 - Nil	5 - Extreme
2 - Minor	6 - Prohibitive
3 - Moderate	

In the assessment no 0 or 6 ratings were applied.   "Prohibitive" in the study was tantamount to disallowing recovery, thereby removing its resource identity.   Instead, where applicable, that portion of an identified deposit occurring in obviously "prohibitive" areas such as underneath townsites, major water systems and the like was removed.   This was not a significant amount of resources.   "Extreme" was considered as a situation where public resistance is presently formidable to the point that the deposit would likely be severely inhibited, reduced, or delayed in its development.   "Significant" was used to apply to those environmental areas that are presently of deep public concern in the region where the deposit is located.   Thus, a "sensitive" issue attached to a deposit identifies it liable for delay or denial based on a single or a group of environmental issues, but allows for the possibility of development after possible delay under imposed restrictions.   The location is important; for example, water resources are much more sensitive in coastal areas than inland due to thinner groundwater aquifer, potential for salt water encroachment, and competition by a higher population density.

Based on recent public exposure, it appeared that the issues of "land" and "water" were of most concern; therefore, a higher rating was given as appropriate in arriving at an "overall" rating code.   In considering the overall, however, it is important to recognize that extraction of a deposit may be denied due to any one of the areas mentioned if there is sufficient public concern.   (It was assumed all assignments of codes 1-3 were non-restrictive in terms of public interest or future concern).

Table 26 summarizes the evaluation and environmental sensitivity encodement of the 102 "C" and "R" deposits in terms of deposit rated "significant" (level 4) or "extreme" (level 5).   Tabulated are only the

TABLE 26. – <u>Environmental sensitivity assignment to Florida deposits</u>

Area of sensitivity	"C" deposit		"R" deposit		Total [1]	
	Number deposits	Tons	Number deposits	Tons	Number deposits	Tons [2]
LEVEL 5						
Land sensitivity						
Short term	-	-	3	257.0	3	257.0
Long term	-	-	2	57.0	2	57.0
Water sensitivity						
Short term	-	-	2	317.0	2	317.0
Long term	-	-	-	-	-	-
Overall sensitivity						
Short term	-	-	2	25.0	2	25.0
Long term	-	-	1	8.0	1	8.0
LEVEL 4						
Land sensitivity						
Short term	4	379.1	18	1179.4	22	1558.2
Long term	1	123.9	10	728.2	11	851.9
Water sensitivity						
Short term	10	870.6	22	1253.1	32	2123.6
Long term	-	-	8	600.4	8	600.4
Overall sensitivity						
Short term	2	269.0	14	1091.8	16	1360.8
Long term	2	174.0	10	975.5	12	1149.4

[1] Short tons dry product.

[2] Some deposits fall into both short and long term sensitivity categories: deposits are therefore <u>not</u> additive down.

categories of land, water, or overall, since it was impossible to develop
information on specific deposits that would be restrictive in terms of
aesthetics, vegetation, etc.

Sensitivity in the area of land is considered more severe for the short
rather than long term, based on the assumption that acceptable reclamation
technology is available and can be applied at a feasible cost. Water
sensitivity is usually only for the short term as the diversion ceases
with operations. Long term water sensitivity is considered for salt water
encroachment or surface water disruption.

No "C" deposits were evaluated as having "extreme" environmental
sensitivity. A maximum of 317 million tons (based on water sensitivity)
was deemed "extreme" for "R" deposits for the short term, and a maximum of
only 57 million for the long term (based on land sensitivity).

Level "4" – significant public sensitivity – was assigned to 10 "C"
deposits, primarily in the area of short term water use. These are pri-
marily developing deposits. When "R" deposits are added, over two billion
tons are similarly classified – over half of the identified resources. Long
term overall sensitivity, probably the more serious designation because it
usually includes several areas of sensitivity, encompasses over 1.1 billion
tons. These resources, if allowed to develop, will likely be allowed under
very restrictive conditions, and in some cases may require a demonstration
of additional mining and reclamation technology before being acceptable.

As a final tabulation, the application of environmental sensitivity
was categorized by cost to develop the potential for combined availability
of Florida's resources in table 27.

TABLE 27. – Total resources: environmental constraint-cost relationship

Sensitivity level of land, water, or overall	Short tons product by production cost							
	≤15	≤20	≤25	≤30	≤35	≤40	≤45	≤50
5 (Extreme)........	0	300.0	66.0	250.0	–	8.0	–	–
4 (Significant)....	67.0	992.9	556.2	291.5	220.2	18.2	9.5	–
1-3(Moderate).......	361.4	91.1	455.3	224.4	66.1	90.5	76.5	5.0

Other Commodities

The mining and beneficiation processes used to produce phosphate rock
result in the handling of vast quantities of minerals other than phosphate
(apatite). The principal gangue present in Florida deposits are: sand
(quartz); limestone and dolomite (these carbonates are usually not of high
quality); clay minerals such as attapulgite, montmorillonite, illite, and

minor amounts of kaolinite, goethite, hematite, and pyrite; and even smaller
amounts of feldspar and heavy minerals. Most of these minerals are abundant
and available in higher concentration and quality from other sources,
expecially as primary or major by-product production.

In the mining and beneficiation of phosphate ore, essentially four major
separations are achieved: (1) overburden, (2) waste clays, (3) phosphate
rock product, and (4) sand tailings. For possible by-product production,
each of these were briefly studied based on the limited data available:

- Overburden – The overburden is usually primarily quartz sand with
  some clay; however, it also often contains leached or waste phos-
  phate (that is, low yield or quality strata). The "leach zone,"
  if present, contains significant concentration of aluminum and
  often uranium; however, the extent of these commodities was not
  investigated in this study. The occurrence of heavy minerals and
  other commodities in overburden has not attracted great interest
  as directly related to phosphate deposits.

- Clays – The waste "clays" produced are potentially valuable as
  future sources of P_2O_5 since they may range in P_2O_5 content from
  5 to 20 percent due to the presence of fine phosphates. Wavellite,
  crandallite, etc., will become a competitive source of P_2O_5 only
  upon the development of economic processing techniques. The clays
  are usually high in Al_2O_3 content, ranging from 7.6 to 16.8 weight
  percent,[27] which may cause a problem with phosphate quality. The

  [27] Lamont, W.E., J. T. McLendon, L. W. Clements, Jr., and I. L.
  Feld. Characterization Studies of Florida Phosphate Slimes.
  BuMines RI 8089, 1975, 24 pp.

  aluminum content of the clay is sufficiently high that it may be
  of interest as an aluminum source in the future. The effect of
  dewatering costs and active silica, calcium, iron, etc., content
  on the availability and quality would require study. Although
  relatively high uranium contents have been reported[28] on

  [28] Texas Instruments, Inc. Central Florida Phosphate Industry
  Areawide Impact Assessment Program – Land Volume VI, Radiation
  Section 4. U. S. Environmental Protection Agency, August, 1977,
  43 pp.

  radium-226 content of slimes (that is, 33-52 pCi/g), no significant
  amount of actual uranium content data is available on clays; and
  careful study of new samples of radium-226 content in the South
  Florida district shows a lower range than that reported (3-20
  pCi/g). Thus, the potential for recovery of uranium from clay
  wastes has not been sufficiently quantified either as to U_3O_8
  content or technical feasibility.

- Rock Product – Since the majority of phosphate rock produced is
  eventually dissolved by sulfuric acid in the process of making
  phosphoric acid, the important elemental constituents of the rock

have been considered for potential by-product production. Today the industry routinely extracts fluorine and has initiated extraction of uranium from phosphoric acid. Extraction of uranium has been spurred by recent price increases, and many chemical companies are developing extraction processes or are constructing recovery units. Other components of rock which may be of interest as future by-products are rare earths, and possibly vanadium. Typical total analysis of phosphate rock can often be misleading since the product composition varies widely with respect to the minor elements. Typical analysis of pebble and concentrate prepared by various chemists[29] are shown in table 28. These compositions may be

[29] International Minerals and Chemicals Corporation, Information Brochure, June 1976.

compared to other examples of typical analyses shown in appendix E. All these analyses were from Polk County production at that time and are not necessarily typical of south, central or north Florida product. The difficulty of element identification is indicated by the absence of extensive U_3O_8 and rare earths data. Altschuler[30]

[30] Altschuler, Z. A., S. Berman and F. Cuttitta. Rare Earths in Phosphorites. U. S. Geol. Survey, Professional Paper No. 575-B, 1975, 265 pp.

reported the occurrence of rare earths in primary apatites and secondary phosphates from central Florida apatites (3 samples), latertoid aluminum phosphate (1 sample Polk County) and hardrock near Dunnellon, Florida (1 sample). Yttrium was very low in bedrock, averaged 110 ppm in the Bone Valley samples, but was 600 ppm in the leach rock. Lanthanum and cerium followed the same pattern with hardrock being low in all 16 rare earth analyses being reported.

During the MAS study specific attempts were made to collect data on product fluorine and uranium content by deposit. Most of the fluorine data were received, and average estimates are not difficult because of an abundance of published data. The estimates ranged from 2.4% fluorine in north Florida to 3.9% for high grade rock product in Polk County, which is typical. In the case of fluorine, there is insufficient variability in reported information to produce a meaningful distribution map. The weighted average of fluorine for the "C" deposits is 3.3% which at present total production represents approximately 1,350,000 short tons per year of fluorine, of which about 900,000 short tons report to phosphoric acid plants in the United States.

Present practice of fluorine recovery consists of scrubbing the vapors from the 30-54% P_2O_5 acid vacuum concentration step and producing 15% and some 25% H_2SiF_6. Additional fluorine is lost to vapors from the digestion step and gypsum cake; that remaining is unvolitized in the 54% P_2O_5 acid. It is estimated that the production of fluorine by this method alone yields only about 30%

TABLE 28.- <u>Chemical analyses of commercial "pebble" and</u>
<u>concentrate, Central Florida Phosphate District</u>

Element	"Pebble"	Concentrate
CaO	46.98	49.76
MgO	00.19	00.29
MnO	00.048	00.044
K_2O	00.13	00.10
Na_2O	00.21	00.24
P_2O_8	32.07	34.21
V_2O_3	00.014	00.010
As_2O_3	00.0011	00.0011
CO_2	03.07	02.59
SO_3	00.59	00.52
SiO_2	09.31	05.68
Al_2O_3	01.29	00.95
Fe_2O_3	01.57	01.31
TiO_2	00.076	00.105
Cr_2O_3	00.007	00.007
U_3O_8	00.018	00.010
F	03.68	03.81
Cl	00.013	00.014
H_2O	01.88	01.52
Organic	00.053	-
CaO/P_2O_8	01.465	01.455
F/P_2O_8	00.115	00.111

recovery[31]/ of the fluorine in the rock.   Thus, a maximum possible

[31]/ Phosphoric Acid. Volume I, ed. A. V. Slack. Fertilizer
Science and Technology Series, Marcel Dekker, Inc., 1968, 1159 pp.

production of only 267,000 short tons per year of fluorine would be
achievable if all plants had recovery units, which is not the case.

Production of synthetic fluorspar[32]/ (calcium fluoride) has created

[32]/ Nash, B. D., and H. E. Blake, Jr. Fluorine Recovery from
Phosphate Rock Concentrates. BuMines RI 8205, 1977, 16 pp.

interest as a substitute for CaF_2 imported for steel production.
Some work has also been done by industry; however, the process is
by no means straightforward, requiring additional research and
development to remove excess SiO_2. Additional fluorine could be
recovered as CaF_2 by pond water extraction. Economic incentives
have also been lacking since natural fluorspar is very competitive.

As mentioned previously, the data on U_3O_8 content of phosphate rock
product offered during this study were sparse due to lack of deposit
data or for confidentiality reasons; therefore, it was insufficient
to produce a meaningful map. The uranium content of the phosphate
pellets has been shown to be highly variable, being a function of
particle size in the Land Pebble district (refer for example to
table 23) with higher U_3O_8 values occurring in the plus 1 mm
material. Relatively high concentrations of U_3O_8 also occur in the
slime fraction from some areas, but this has not been the case
(based on limited data) for the South Florida district. These clay
values, however, have not been of great interest except when con-
sidering waste disposal.

In central Florida, the pebble ranges from 0.64-1.36 pounds of U_3O_8
per ton of P_2O_5, while the flotation concentrate ranges from 0.3-1.0
pound of U_3O_8 per ton of P_2O_5. The concentration of U_3O_8 can range
as a function of the percent pebble in the rock shipped and the
grade of the rock, even from the same deposit.

The lower grade rock products produced from the South Florida
district contain less uranium. The average percent of product as
pebble (see figure 10) also decreases sharply south of Polk County.
Thus, the product from this area is estimated to be in the range
of 0.3-0.5 pounds of U_3O_8 per ton of P_2O_5 compared to the 0.8-1.0
range for the Polk County area. Caution should be applied to use
of these preliminary estimates.

• Tailings - The abundance of flotation tailings and the availability
of the more superior sand deposits in Florida have precluded all
but minor use of tailings for commercial purposes. Sufficient heavy

minerals occur in the flotation feed to most of the Central Florida
plants to be of interest. A USBM study[33] investigated methods of

[33] Lamont, W. E., O. R. Brooks, I. L. Feld, and T. N. McVay.
Rutile, Ilmenite, Zircon, and Monozite for the Central Florida
Pebble Phosphate District - Occurrence and Beneficiation. U. S.
BuMines, Dec., 1968, 29 pp.

recovering heavy minerals in the plant feed. The heavy minerals
report to both the tailings waste and final concentrate
extracted in the flotation process. The study estimated that
3,000-6,000 tons of rutile, 28,000-55,000 tons of ilmenite,
9,000-19,000 tons of zircon and 400-800 tons of monazite passed
through central Florida plants in 1968. These tonnages are not
large when compared to the total tons of material processed by the
mines. Recovery of a reasonable portion of these heavy minerals is
technically feasible, but determined, after studies by a number of
the companies in the industry, not presently economically feasible.
Potential for eventual recovery seems small.

PRODUCTION CAPACITY

The ability of the industry to sustain or increase its present rock production in Florida is of national interest. This capability will determine the future course and location of domestic production, and ultimately affect the United States' position in the world market. Florida resources identified in this study, if all are eventually recovered, would satisfy the state's present production level for one hundred years. At issue, however, are (1) the availability of these resources with time in consideration of mining cost, product grade, technology and environmental constraints, and (2) the future demand for Florida production in terms of market and production capability. Previous sections have characterized the resource availability. The future position of Florida in terms of phosphate rock production capability and market position are dependent on:

- Domestic and world demand for phosphate rock at desired grade and/or fertilizer products. Florida's potential for exporting phosphate rock depends on product grade requirements of the international market, world demand, and future production by other countries. As noted in the grade characterization section, Florida's higher grade land pebble rock is held by existing producers, with additional known high grade resources being limited to the Hardrock district. Resources of this grade are limited and present customers will eventually have to lower their specifications or go to other sources. Florida, however, can maintain its P_2O_5 position in the world market by rock upgrading (at additional cost) or developing additional facilities for phosphoric acid and other high analysis chemical production for export. Either alternative could maintain Florida's position in rock production if pressure for high grade export rock materializes.

  Developing production by other countries will influence the present demand. A number of countries in Africa, Asia, and South America are developing a basic supply position in order to improve international trade balance, establish mineral independence and provide employment. New mines could be government subsidized to the extent necessary to complete with international prices or – by imposition of import restrictions – support domestic production. A few countries may become sufficiently competitive with major world producers to produce rock for export.

  Offsetting this new production to some extent will be the food demand of a burgeoning world population in terms of both growth and dietary improvement.

Domestic phosphorus demand has been estimated to increase at only
slightly over two percent[34]. This estimate is based on a

[34] U. S. Bureau of Mines. Phosphate - 1977. BuMines Commodity
Profile, May, 1977, 18 pp.

regression analysis study linked to population growth and dietary
demand. The domestic demand is also dependent, however, on foreign
demand for United States food products and subsequent shifts in
population or diet.

- Environmental and/or regulatory constraints: Future government
regulation and policy can serve to promote, discourage, or limit
production either through direct development control or costs
related to taxes, tariffs, and meeting environmental requirements.

- Availability of natural resources: Future conservation practice
related to water and/or energy, etc., could control production
rate. Energy, because of its rapidly escalating cost, is taking
prominence in design and operations. Water could become an
inhibiting factor as a result of competition in areas of limited
supply, particularly coastal regions.

- Technological development: The history of the industry, as pre-
viously noted, has been marked by key breakthroughs in production
cost of phosphate recovery. Significant advancements in the mining,
beneficiation of rock, or fertilizer manufacture technology could
suddenly affect industry cost or recovery bases now in effect.
Technological improvements are definitely possible in the areas
of mining by-products, calcareous ores, beneficiation recovery,
and by-product recovery such as uranium, heavy minerals, etc.
Uranium extraction alone could, with time, provide additional
incentive to significantly affect the economics of fertilizer
manufacturing.

Future technological advances in agronomy may be another key
element. The discovery of new fertilizer combinations, studies
of optimum fertilizer rates, and changes in dietary needs for food
preference could have substantial long term effect on P_2O_5
requirements.

- World calamity: Phosphate production growth has been previously
interrupted by previous world conflicts. World famine, pestilence,
etc., are other unpleasant possibilities.

- Economic incentive: This factor forms the basis for most pro-
jections in attempting to determine the ability of a company to
compete with other domestic and foreign sources. The basic con-
sideration is the capability for rock production at a sufficiently
low cost to provide an adequate profit margin to continue
operations and attract necessary capital.

In 1977, according to preliminary Bureau of Mines figures, Florida (including one operation in North Carolina) produced about 40,500,000 metric tons (44,700,000 short tons) of phosphate rock. Florida's share of the production represents about 90% of its existing capacity. Adding the individual operator's published production capabilities, this operating factor (that is, 90% of rated capacity) approached maximum short ton industry capability. The 1977 production rate of a percent of stated capacity for individual companies was mixed, ranging from maximum output capability to low operating factors in new mine startups. The 90% operating factor for industry long term production of combined individual plant capacity is, in the authors' opinion, most representative for future projections.

Historical Production Rate

As mentioned previously, prior to 1965 industry production doubled with every decade, which approximates an average compounded rate of about seven percent. Figure 49 illustrates the production since 1955 and the associated growth rate for characteristic time increments during the period. The rate has been subject to sudden changes due to market supply-demand. Large additions in capacity, such as occurred in the middle 1960's, produced a market glut that seriously depressed both production and profitability in the succeeding years. In 1974, demand again reached capacity, and combined with foreign market price increases, dramatically increased profitability and development incentive.

Projecting future growth from historical patterns is risky and possibly misleading; however, the rock production demand of the last decade may be considered as the most representative of existing conditions that would affect production incentive. The period since 1965 shows a 2.4% growth rate per year, and closely approximates projections made recently by the Bureau of Mines. It should be considered, however, that from a conservative position this has been a "flat period" in mine development and world demand. The influence of the longer term larger rate also suggests that a slightly larger projection may be appropriate.

Existing and Projected Mine Capacity

Figure 50 graphs both the projected decline in existing production capacity and the potential capacity from the addition of new mine development proposed for the coming decade.

The existing production, considering a 90% operating factor and assuming a continued demand,will hold to nearly its present level until about 1987, when it should reduce dramatically to less than one-half its present level. Another substantial drop may occur in the mid-1990's with complete depletion of presently exploited deposits by the turn of the century.

The projected or planned deposit development is substantially in excess of the 3% projected growth in demand shown for the coming decade. Should such a projection be accurate, some new mine development will be delayed until
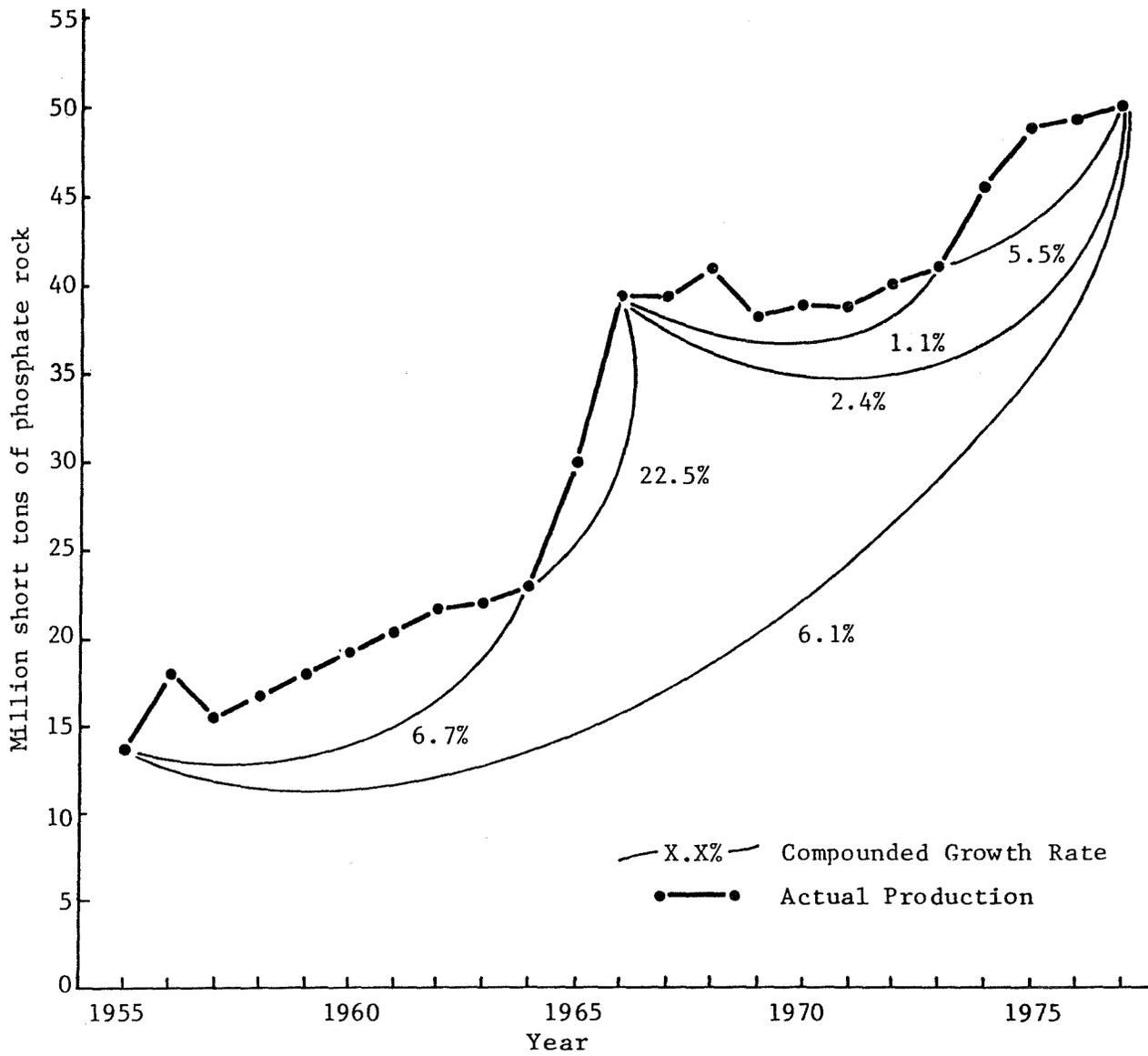
FIGURE 49. – United States production, 1955–1977.
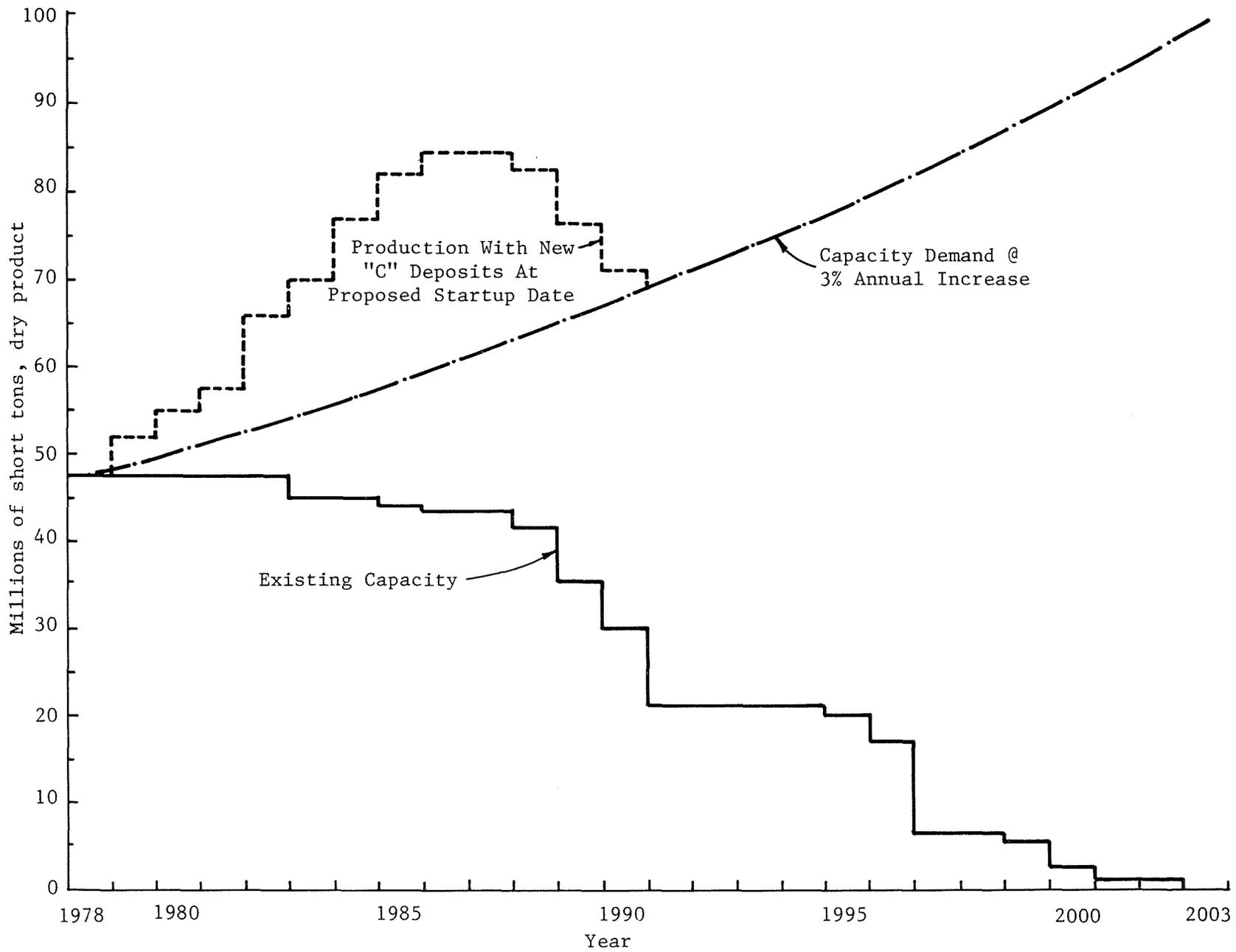
FIGURE 50. – Existing and proposed production capacity.

the additional capacity can be absorbed. The supply projection, however, will fall within a 6% growth increase and thus shows the sensitivity and importance of accurate projection in future demand.

At the 3% projection, deposits classified in this study - if all were allowed to develop without cost or other restrictions - could meet the capacity demand illustrated until the year 2005, after which time total production would fall short of the 100,000,000 short tons per year. This represents no displacement of Florida's present position within the domestic or world market during this period. Beyond that time or capacity, additional Florida resource identification would be necessary to maintain market position, although production would continue at reduced levels well into the century.

Projected Product Grade

A previous section on economic classification distributed product grade in the identified resources by cost, "C" deposits, and existing producers. The graphs plainly illustrated that the higher grade resources are within the Hard-rock district, which may at that time undergo some development due to economic incentive derived by substantial grade price differential, if demand for the higher grade rock continues.

From the remaining identified resources, it is apparent that Florida will be able to maintain grade levels of about 68% BPL (present production average) for a substantial period of time - over 2 billion tons of phosphate rock resources were identified with a 66-70% BPL (30-32% P_2O_5) grade range. Over 1 billion additional tons are identified above 62% BPL (28% P_2O_5). It is therefore believed that Florida's capacity will not be grade sensitive in the foreseeable future.

The magnesium content of some lower grade product has been previously discussed. The impact of this factor is not quantifiable. The study actually identified only 300,000,000 tons of product from five deposits as being greater than 1.4% MgO (a deposit selection criteria), although it is likely that the actual amount is substantially more for product processed by conventional methods. It appears that technology is available to substantially reduce MgO included as free dolomite, providing sufficient incentive is provided.

Projected Production Cost

A previous section described the method by which production costs were determined for each "C" deposit by the "case" method. The assignment is believed to be accurate for typical cases within 10%. By modeling the costs developed in the cases on cost-sensitive deposit characteristics, a cost calculation was developed as well for "R" deposits. Using such development by individual deposit, the resources were thus subject to characterization by relative cost.

In figure 51, using a constant increase in <u>capacity</u> demand of 3%, the additional capacity needed beginning in 1979 to supplement the existing (and eventually declining) mine capacity will be filled with deposits of higher production cost. The increased costs are primarily a result of lower quality (less concentrated) ore and higher depreciation costs (capital investment). Using the case designations, future production necessary to supplement "Case I-II" production will be derived initially from "Case IV" then "Case V" and higher quality "R" deposits. If the basic premise is that deposits will be developed to meet projected increased demand at an orderly rate based solely on priority according to lowest production cost, the remaining deposits and their assigned cost may be used to project the average increase in production cost to meet future demand.

For the compilation, existing mine production costs averaging $12.93/ short ton of product (<u>1977</u> basis) were used as a base. Deposits were then added in order of lowest cost and at the capacity proposed by "C" developers. Initially, most added production was "Case IV" or that assigned mines in the Northern and South Florida districts ($18.30). Subsequent deposits were added irrespective of announced startup or identity other than capacity and cost. By the year 1991, all "Case IV" deposits were in production and other higher cost deposits were added in order of lowest cost priority. In making the compilation and projection the following assumptions were followed:

- All costs are in constant <u>1977</u> dollars - no escalation considered.
- The 90% operating factor experienced in 1977 will remain constant, regardless of total production.
- Slowed depletion of existing reserves by the operating factor extends individual mine lives by 10%.
- The existing rock inventory (about 14 million short tons as of January 1, 1978) will remain constant.
- Capacity demand will increase at a 3% annual growth rate.
- Florida will hold the present share (about 75%) of total United States capacity.
- Costs assigned are those developed in this study through case studies by computer modeling methods.
- New deposit development will be permitted when required at the most feasible capacity irrespective of any technologic or environmental constraint.
- No technological breakthrough will occur to significantly reduce costs.
- No new uncontrollable cost will be imposed, as for instance taxes, etc.
- No increase in future reserve cost will occur.

Using the above assumptions, the projected cost escalation in <u>constant 1977</u> dollars is somewhat predictable as shown on figure 51. The graph shows that as existing low cost production is gradually supplemented by that of higher cost production, a gradual small rise of slightly over 1% per year is experienced until the late 1980's, when a number of existing mines
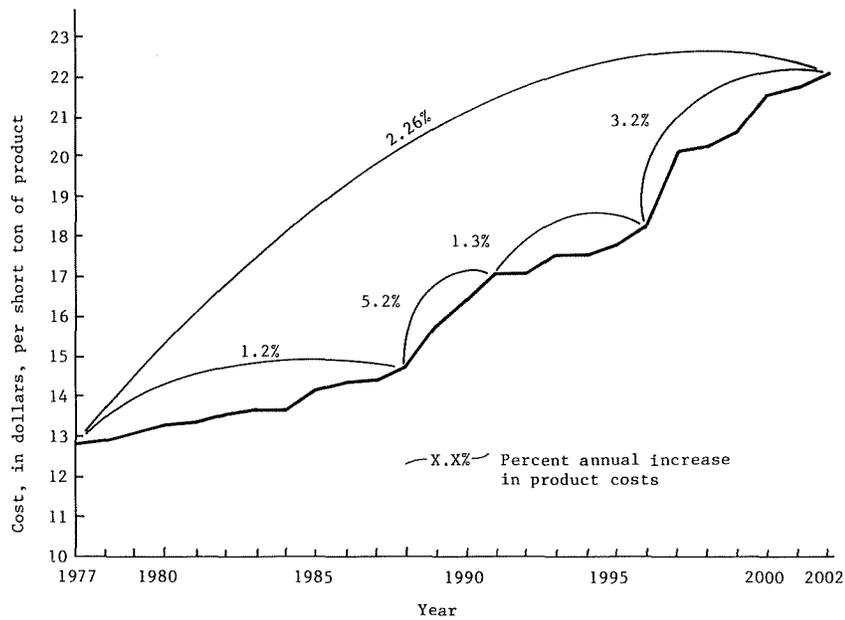
FIGURE 51. - Projected product costs (constant 1977 dollars) at three percent annual increase in production rate, 1977-2002.

are depleted. New capacity is then added at the rate necessary to not only supplement but also substitute for that depleted. A market increase of over 5% annually occurs during this five year period, and then rates of increase similar to the 1977-1988 period prevail until a second phase of existing mine depletion takes place after 1995. The overall annual increase for the twenty-five year period is 2.26%. Note that costs do not rise above the twenty dollar level for twenty years. The reason for the seemingly low increase is the abundance of identified resources available at production costs of less than twenty dollars. The costs shown are, however, probably somewhat low from that to be actually experienced due to (1) higher unit costs for mines during some period prior to final depletion or immediately after new plant startup due to lower production rate (higher incremental fixed costs), and (2) higher costs related to meeting environmental or regulatory constraints, and (3) undefined infrastructure requirements for some deposits, particularly those in northern Florida. Despite these additional costs, the growth in cost for Florida production, if allowed to develop at the required rate to meet capacity demand, will not rapidly escalate in the foreseeable future in terms of constant dollars.

There is very little reported data to indicate historical cost experience. It is suspected, however, that prior to the past five years there was in fact a long term decline in operating cost (constant dollars). To support this observation is the fact that (1) mines, including the more modern ones, have been able to operate within high quality (in terms of rates of concentration) ores; (2) the fact that mines were capable of surviving, and in fact attracting capital, during the ten year period prior to 1974 when constant dollars prices did not increase; and (3) the steadily improving extracting equipment and increased capacity of operations. This being the case, the increase represented by the graph in figure 51 is a significant milestone in Florida industry; recognizably lower quality ore will be the basis for future increases in costs.

The projected cost increase is misleading to the extent that it intentionally omits increases due to escalation. Inflationary increases could probably be discounted, but escalations in cost-sensitive areas such as energy could cause sharp increases in unit cost that would be significant if not uniformly applicable on a national or world scale.

The above discussion indicates that Florida phosphate will continue to be available at acceptable grade and unit cost well into the future, based on considerable quantities of acceptable grade rock and apparent low constant dollars escalation. However, comparison with other domestic and world demands would be necessary to determine the relative quality of the resource and its position and potential for future demand growth.

CONCLUSIONS

This final section is a listing of conclusions as a result of the study pertinent to an evaluation of the state's resources. Elaboration or justification for the enumerated points is contained within the body of the report.

1. Over 4 billion short tons of recoverable phosphate rock product from over 33 billion short tons of in place ore (see tables 22-25) were identified in the study at various levels of grade, production costs, and probability from DeSoto County north to the Georgia border, from 102 deposits shown on table 21. In addition to these identified, the state has additional phosphate resources of undetermined extent from the following major sources that are potentially identifiable through additional exploration and/or technology:

- "East Coast" district.

- P_2O_5 extracted from previous mining debris, particularly slime ponds in the Central district.

- Phosphatic carbonates (Hawthorn) underlying more clastic (and usually richer clastic) Bone Valley and Hawthorn phosphorite beds.

- "Hardrock" ore - poorly defined, particularly on the western flank and in the northern portion - a source of higher grade product.

- Phosphatic concentrations have been noted on the ocean floor offshore of the northwest and upper east coast portions of the peninsula.

2. The eventual recovery of the identified resources is primarily based on prevailing mining and beneficiation technology, environmental sensitivity, and economics. Of the resources identified, over 1.5 billion short tons of recoverable product is projected to cost less than twenty dollars/short ton to recover, on a present-day dollar base, and classified less than extreme in environmental sensitivity (see table 27). An additional one billion tons is available at less than $25.00 . Table 22 illustrates the distribution by cost and grade in various sectors of the state. The table is confined to resources presently identified and includes all levels of probability. The portion of this identified resource eventually to be recovered is dependent on future economics and environmental constraints. Future improvements in mining and process technology could be a significant determining factor both in recoverability and economics.

3. The uranium resource as a potential by-product or co-product was inadequately defined by this study. Insufficient data was made available to the study to analyze the resource potential as a phosphate rock or waste constituent to any great degree of confidence. The Department of

Energy has underway a study of such potential that will include Florida
phosphate resources. The uranium values attached to each district in
the study, however, are believed typical.

4. Product grade of deposits is sufficiently high to meet current
average production grade well into the future - over 1.5 billion tons
of 66-70% BPL rock were identified at costs less than $20.00/short ton (see
figure 47).

5. Higher product grades are more limited in supply and will be
essentially depleted in the coming decade. To maintain the United
States' current level of production utilizing lower grade rock, it will be
necessary either to: (1) additionally beneficiate rock as practical (at
some additional costs and loss of recovery), (2) develop higher grade
resources as practical in the Hardrock district (probably higher cost
and lower production rate), or (3) construct additional acid production
capacity to convert lower grade rock product to various high grade products.

6. Future mining will continue to consume large amounts of natural
resources, particularly water and energy. Conservation measures and
mining or process improvements that reduce demand will become increasingly
important.

7. Regulatory and environmental control of operations is presently a
significant factor in development planning, operational procedures
(including monitoring), and the resulting production cost. This is expected
to continue as the state grows in population, thereby increasing land and
resource demand.

8. The present production capacity can be maintained for nearly ten
years by existing mines; new mine development will be necessary to supplement
loss of operating factor due to older plants and any increase in demand
(see figure 50). The total Florida capacity can be made available to
meet a total projected demand increase of 3% per year for the next twenty-
five years from the deposits identified if all such deposits become
environmentally, technologically, and economically viable, and Florida
would continue to carry its share of total domestic production. At that
time (about 2002) capacity demand for Florida would exceed one hundred
million tons annually. The identified deposits, although falling short
of capacity demand at that level, would contain sufficient resources to
continue production for an extended period at a high rate of production.
The 3% demand is not a projection of this study, but used as possible for
purposes of projecting future costs and capacity requirements. Figure 49
indicates growth rates over the past twenty years in incremental periods.

9. Production costs are expected to increase only modestly for the
next decade in constant dollars at the 3% growth rate, although specific
non-controllable items could escalate more rapidly than the base in-
flationary rate. Significant cost increases in energy, taxes, pollution
abatement, reclamation, etc., could upset the projection. In any case,
these unpredictable increases notwithstanding, Florida rock will increase
at a modest rate in cost as a result of larger capital investment to recover

lower quality ores and should successfully maintain a competitive production cost for some time.

10. This slow rise in constant dollar cost and ore quality production availability notwithstanding, the need is present to develop technology that will further reduce cost, increase resources, mitigate environmental impact, or reduce resource demand. Significant progress has marked past history of the industry in all of these areas. There appears sufficient social and economic incentive for this to continue. Considerable additional work is warranted in the following specific areas:

Resources

- Ongoing research in alternative P_2O_5 recovery methods of both primary ore and clay wastes.

- Uranium resource identification and recovery projection for future growth as a by-product of phosphate processing

- Offshore resource investigation. Some information is presently available from active marine institutes, the USGS, etc.

Mining

- Improvement in present strip mining technology for deeper ores, or development of alternative viable recovery methods.

- Alternative material transportation methods - primarily as an aid to reducing energy costs.

- Continued waste clay disposal studies, primarily to promote improvements in land reclamation but also as an identified potential for decreased operational water demand.

- Continued studies in land reclamation and reuse. Sophisticated planning and technology is being applied in a rapidly growing science necessary to ameliorate public attitude.

Beneficiation

- Increased recovery in ore benefication from improvements in desliming, sizing, flotation recovery (improved reagentization and efficiency).

- Development of upgrading processes for low and near-acceptable product grade pebble by carbonate and silica liberation and P_2O_5 concentration.

- Recovery of P_2O_5 from phosphatic carbonates underlying most of upper peninsular Florida, primarily within the Hawthorn formation.

- Carbonate rejection processes.

● Future recovery or utilization of by-product (gypsum, heavy minerals, etc.).

As a result of this study, it is recommended the Bureau continue its efforts in several present research projects, including alternative P_2O_5 recovery processes, P_2O_5 liberation from lower grade ores, and dewatering of phosphate slimes. New projects in reclamation technology and offshore resource identification would also merit consideration. Continued development of information on world resources is essential to provide a more valid basis for projection of the U. S. position in future world production and demand. Of particular value would be the establishment of long range foreign production capacity of deposits being presently identified, developed or produced, and the relative quality and cost of the commodity.

GLOSSARY

BPL - Bone Phosphate of Lime is tricalcium phosphate ($Ca_3(PO_4)_2$),
usually with impurities, most commonly fluorine. Most Florida
phosphate rock is a fluorapatite ($Ca_3(PO_4)_3 F$). BPL is used
to "grade" the phosphorus content of the rock. It is also
often graded in P_2O_5 (phosphorus pentoxide) content (1.0% BPL =
0.458% P_2O5).

"C" deposit - A term used by The Bureau of Mines Minerals Availability
System (MAS) to categorize a deposit presently exploited or
scheduled for exploration in the immediate future. Deposits so
designated allow for extensive input data, including cost in-
formation, rock characteristics, mining and beneficiation data,
and associated commodity information. For this study, deposits
so designated in Florida are either presently being mined, or
have announced intentions by developers for future mining.

Concentrate - The phosphate rock separated from silica gangue by
flotation; nominally the particle size processed is from 1.0-
0.1 mm. "Concentrate" product is differentiated from "pebble"
product, both of which make up the "phosphate rock" commodity.

"L" deposit - A MAS term used to identify deposits for which there is
little available specific information, particularly lacking in
quantitative resource data. Such deposits are only entered by
identification, with no resource attached.

MAS - (Mineral Availability System) The U.S. Bureau of Mines system
for evaluating, classifying mineral resources. Known resources
are evaluated and classified by deposit for entry into a
computer storage and retrieval system that yields individual
mineral deposit availability data, combined deposits data, or
analytic output through program design.

Ore - Identified phosphate that is economically and legally
extractable, and from which phosphate rock can be feasibly
extracted from the gangue wastes (usually silica and clay).
The rock from such ore is the reserve. In Florida, phosphate
reserves and resources are expressed in tons of recoverable
product rather than ore.

Pebble - Phosphate rock separated from ore usually by disaggregation
and screening. Most pebble is classified greater than 1.0 mm in
size. In Central Florida, most pebble phosphate has sufficient
phosphorus (% BPL or P_2O5) content to be sold as a product with-
out further upgrading. This is not true of districts other
than the Hardrock, where past phosphate production has produced
primarily only a pebble product.

Phosphate rock – The apatite commodity separated from ore, inclusive of both pebble and concentrate phosphate product of mining and beneficiation.

Phosphorite – Rock bearing significant or recognizable quantities of phosphate. In Florida, it occurs exclusively as a marine apatite, either in a carbonate or clastic gangue. Land pebble phosphate is a term used to differentiate phosphorite occurring on land (rather than river) in a predominantly clastic (pebble sand and clay) sedimentary rock. The term phosphorite in this report is used to identify earthern sequences containing sufficient phosphate to be recognized as a resource material. Ore is used as a term to designate economically and legally recoverable phosphorite.

Probability – A MAS method of ranking a resource quantity based on level of confidence. A single matrix (ore of constant grade) may have several resource quantities, based on probability of occurrence. Resource quantities decrease as probability increases. In this study, however, probability was limited to identifiable quantities; that is, lower probabilities do not include hypothetical extrapolations.

"R" deposit – A MAS term used to quantify and identify deposits not scheduled for production in the near future.

Reserve – Previously defined as that portion of the identified phosphate rock resource which can be economically and legally extracted at the time of determination.

Resource – Specific deposits of phosphate rock, identified in terms of recoverable product. Criteria for resource identification used in this study are shown on table 19. Hypothetical or speculative resources were not included in this study.

APPENDICES

Appendix A. - The Minerals Availability System

(Extracted from Information Circular 8654)

MAS defines the physical and commercial availability of mineral resources. Known resources are evaluated and classified by deposit for entry into a computer storage and retrieval system that yields individual mineral deposit availability data, combined deposits data, or analytic output through program design.

Input Data

The Resource Classification Manual provides classification and coding procedures for adapting mineral deposit evaluations to automatic data processing. Commodity input priority is based on such criteria as (1) forecasted supply-demand disparities; (2) relative essentiality of the commodity to the national interest; (3) geographical distribution of supply; and (4) known occurrences of domestic resources. Those deposits having the greatest supply potential are examined first; expansion of the files is then carried to marginal and submarginal deposits.

Entry records for each deposit are as follows: Identification; Deposit Name; Owner/Operator; Location; Geographic and Environmental Characteristics; Exploration; Rock Description; Economic and Gangue Minerals; Deposit Characteristics; Probabilistic Grade-Quantity Matrix; Underground Mining; Surface Mining; Beneficiation; Transportation, and References and Comments.

The Location record describes a point location in terms of either the Latitude-Longitude Grid or the Universal-Transverse-Mercator Grid. The Geographic and Environmental Characteristics record includes a judgment of the geographic-environment sensitivity to mineral extraction. Shape and dimensions of the deposit ore zone are contained in the Deposit Characteristics record.

The Probabilistic Grade-Quantity Matrix provides for entry of grades and associated tonnages for each of up to six products contained in the deposit. Evaluations of the in situ resources are made with some degree of uncertainty. Instead of ranking resources by the commonly used confidence terms of "measured", "indicated", and "inferred", a subjective probability assessment is made to express the reliability of information about each described tonnage. Estimates associated with specific confidence or certainty levels can be related and utilized with integrity regardless of how the information was derived.

The system provides for entry of multiple grade estimates. Grade values are selected by reviewing deposit characteristics and mining methods to demonstrate the range of possible mining grades. Entry of multiple average grades gives a variety of options for exploiting a

deposit under different economic conditions. Information for up to five average grades may be entered into the system. Tonnages are cumulative from one grade to the next in the matrix.

MAS resource-quantity figures are estimates expressed over a range of probability that present the total evaluated potential for a deposit or commodity, not just safe or minimum values. Estimates are not better because they can deliberately mislead and misinform. Probability assessment provides tonnage estimation at five levels of probability (0.90, 0.75, 0.50, 0.25, and 0.10). Use of probability evaluation allows expression of the availability risk apparent to the resource classifier. Tonnages are cumulative between probability levels.

Complimentary cumulative distribution is used to display the grade-quantity relationship because the conventional distribution curve would relate high probability with greater resource quantities. Statistical and mathematical theory supporting MAS probability assessment is omitted in this presentation; a separate circular formalizing theory and practice is planned.

The mining records contain data that define and describe existing or proposed mining procedures with applicable capital costs and operating costs required for extraction. Included are data describing rock support characteristics and character of the ore.

Beneficiation data include recovery factors for the deposit products, recovery methods, plant capacity, and estimated capital and operating costs.

Extraction system evaluation procedures are conducted as an independent function from resource classification. This activity includes individual mine, mill, and smelting studies and extraction-system model development.

Transportation data include the types of material being shipped, the mode of transportation, the distance, and the final destination. Transport costs are generated by computer algorithm and cost models.

Evaluation Procedures

MAS accepts minerals information at all levels of availability risk, expressed by suitable probability levels. This enables MAS to accumulate mineral deposit data from all possible sources and to meaningfully merge the information into a usable system. The system's versatility and broad latitude of allowable judgment should help mineral resource evaluators in the search for and entry of data into MAS.

Deposit Priority Determination

The initial step in deposit evaluation for a commodity is to make a broad literature search for names and locations of deposits and to get an approximation of their potential resource magnitude. State geological departments and universities with mining schools usually have unique information, and in some cases private consultants or mining companies can provide valuable assistance.

When sufficient deposit information is accumulated, work priority lists, by State, are made. A suggested deposit ranking system variable on judgment of the investigator, is--

1. Operational deposits with an established reserve.
2. Developing properties with an established reserve.
3. Paramarginal deposits with a significant potential.
4. Geologically favorable occurrences.

Preparation and use of the priority list allows system input to be tailored to funding limits. The more important resources will be evaluated and entered first.

Deposit Evaluation

After making a priority list of potential deposits, the next step is to accumulate all available information on individual properties. The investigation depth can range from library research to visiting the property and obtaining detailed information in the form of maps, private reports, and reserve data from the mine owner or operator.

Library source materials are Bureau of Mines publications and open-file reports, Bureau of Mines mineral property files, U. S. Geological Survey publications, State geological survey or mining department publications, mining periodicals, mining industry annual directories, and company annual reports. State geological survey mineral property files generally contain much unpublished material.

Deposit File

All information accumulated on individual properties is organized into a permanent file; retention is in the Bureau's Field Operation Center making the investigation. A completed file contains--

1. The completed MAS classification - record work sheets.
2. Copies of all pertinent private reports and geologic maps.
3. Copies of all pertinent material from literature research.
4. Production records.
5. U. S. Geological Survey topographic maps used for location and geographical purposes.
6. Photographs, trip reports from property visits, and transcripts of telephone conversations pertinent to the deposit.
7. A diagrammatic sketch showing the general configuration and dimensions of the ore body and its relationship to the surrounding country rock.
8. Concise (about two typewritten pages) file report that brings together and summarizes all supporting data, and explains how the resource matrix numbers were derived.
9. A complete list of references and source materials used.

Item 7, the diagrammatic ore body sketch, is necessary to reinforce any mine maps and cross sections used, and to support the resource estimator's reasoning for the matrix tonnages. The sketch is made on 8- by 10-1/2 inch paper, and is in black and white so that detail will not be lost in machine copying. It is suggested that a simple orthographic projection or modified block diagram representation be used. The sketch need not be to scale, but overall dimensions of the block and included ore-bearing zones are given. The sketch should show--

1. Ore bodies or ore-bearing zones, with approximate dimensions.
2. Relationship of country rock geology to ore (rock types, contacts, structure).
3. Surface topography, if possible.
4. Relative positions of mine or exploratory workings, where possible.

Item 8, the summary file report, is important because it brings together all the diverse material used in describing the deposit and in generating the Probabilistic Grade-Quantity Matrix. The file report is about two typewritten pages and contains the following items:

1. Property location. - Location data should be given in more detail than possible in MAS records. It includes access, mileage from known points, and a map where necessary.

2. History and production.

3. Detailed ownership data. - This information includes mailing addresses and phone numbers of the current owners and operators.

4. General geology. - Information should be from the best available sources and in sufficient detail to support the Probabilistic Grade-Quantity Matrix.

5. Description of the ore bodies. - This section describes the ore bodies in regard to shape, attitude, mineralogy, genesis, and dimensions, and should locate the resource blocks by description and map reference. (The diagrammatic sketch referred to previously is used here.)

6. Description of Probabilistic Grade-Quantity Matrix construction. - This section includes all data necessary to explain, support, and justify resource grades and tonnages used in the matrix. All published reserve-resource figures used should be referenced here, and all derived numbers should be supported by explanatory text, by calculations, or both. The description in the section on ore bodies is drawn upon for dimensional data, and the diagrammatic sketch (plus any other maps or sections thought necessary) is used to illustrate and support derivation of resource numbers.

7. Mining and beneficiation methods. - Information supporting these MAS record categories is referenced here, and brief

descriptions of mining and milling methods are entered. Any
unique problems encountered in mining or milling that might
not be obvious in the records should be explained. This section
contains the supporting calculations for the swell factor and
the percent of waste rock in the mining records.

MAS Record Completion

Once the supporting data file is set up, MAS record work sheets
are completed as outlined in the manual. A primary concept to keep
in mind concerning the Probabilistic Grade-Quantity Matrix is that the
system is designed to accommodate all levels of information from varied
sources and, by probability assessment rankings, to merge together
grade-quantity information for two or more deposits. If resource
information on a deposit is scanty, and general information is like-
wise of low caliber, then the resource evaluator should use caution
and good judgment in approaching the higher probability levels and
should not be unduly concerned with "filling in all the spaces" in the
matrix.

A general approach to the Probabilistic Grade-Quantity Matrix
consists of the following three steps:

1. Definition of the ore bodies or mineable resource blocks.
2. Determination of as many mineable grades as possible.
3. Recording the appropriate tonnages, as determined by
   (in a rough order of importance)--
   a. Published reserves.
   b. Resources calculated from reliable data.
   c. Projected mine life based on size of operation,
      rate of production, size of investment, amount
      of exploration of development, and comparison with
      similar operations.
   d. Resources estimated by reliable sources.
   e. Geological inference.
   f. Past production.

Records covering mining and beneficiation are completed by the
resource evaluator as outlined in the manual, with the exception that
mine and mill systems and costs are evaluated by specialists in these
fields.

Appendix B. - Important dates related to the development
of the Florida phosphate industry prior to
World War II

Year	Event
1837	Phosphate rock was discovered in South Carolina.
1863	Phosphate rock first mined in Quebec and Ontario, provinces of Canada.
1867	Mining was started in South Carolina.
1880	Hard rock was identified at Hawthorne, Alachua County.
1881	Captain J. Francis LeBaron discovered river pebble in Peace River near Arcadia.
1883	Phosphate first mined at Hawthorne.
	A dredge in Tampa Bay encountered phosphate limestone.
1884	Railroad reached Tampa.
	Phosphate was discovered at Crawfordville in Wakulla County.
	Phosphate was discovered in Devil's Millhopper, about 5 miles west of Gainesville.
	Phosphate boulders were found in Preston's Sink near Waldo in Alachua County.
1885	River pebble was identified in Peace River at Ft. Meade.
1886	Phosphate was discovered in Tennessee.
1887	Land pebble discovered east of Ft. Meade.
1888	Ten cars of river pebble were produced and shipped from the Arcadia area to Atlanta.

1889   Albertus Vogt discovered high grade hard rock near Dunellon. The

Marion Phosphate Company began operation late in the year.

1890   Two companies were active in land pebble area; one at Phosphoria

and one at Pebbledale.

1891   First shipment of land pebble made by Pharr Phosphate Company from

Pebbledale.

South Carolina raised severance tax from $1.00 to $2.00/ton.

1892   Canadian phosphate mines ceased to operate.

Rotary dryers displaced other methods of drying.

Steam driven 6-10 inch centrifugal pumps, mounted on barges,

were used to mine the matrix.

There were more than 215 mining companies in the state.

1893   A financial panic occurred.

1894   Florida out-produced South Carolina for first time.

Tennessee began production.

1895   There were more than 400 phosphate mining companies in the state.

1900   Eighty-one companies were mining phosphate in Florida. Shortly

after 1900, overburden was removed by hydraulic methods.

1905   Major portion of Florida's phosphate rock was produced at the

headwaters of the Peace and Alafia rivers, and southward along the

Peace River.

Started building railroad from Hull, about 10 miles below Arcadia,

to Boca Grande.

Steam shovels had largely replaced mules and "scrapers".

1906	Messrs. E. C. Stuart and D. B. Tilgham purchased major portion of a Hardee County tract, now owned by C. F. Industries.
	The Western States began production of phosphate rock.
1907	Forty-five companies were operating in the hard rock field.
	Steam turbines were introduced to generate electricity at central power houses.
	New mines were completely electrified.
	There was a financial depression.
1908	Production of river pebble ceased.
1909	Twenty companies were mining in 74 locations in hard rock district.
1910	Railroad was completed from Boca Grande to Mulberry.
1911	The U. S. used more phosphate than it exported.
	Sixteen companies were operating in the land pebble district, and fourteen companies were operating in the hard rock field.
1914	Most companies shut down at the beginning of World War I.
1919	Seventeen companies were operating in Polk County.
	The industry was shut down by a bitter strike.
1920	South Carolina phosphate mining was shut down.
	First new electric dragline, 225-B, was purchased by Southern Phosphate Corporation and assembled near Fitzgerald Cemetery. It was later moved to San Gully Mine and then sold to Phosphate Mining Company, where it was named the "Captain Ed."
1921	A farm depression occurred.
	Draglines removed the overburden at most mines.

1923	Swann Chemical Company purchased phosphate land and/or minerals in Cook's Hammock, Layfayette County. Uncle Henry Clark initiated "mining on the hill" at Phosphate Mining Company, now the Mobil Chemical Corporation.
1926	Steel replaced wood in construction of washers.
1927	First pilot flotation plant was placed in operation; phosphate was floated with fatty acid reagents.
1929	Phosphate Recovery Corporation's Plant No. 1 started up.
1930	Phosphate Recovery Corporation's Plant No. 2 started up; this plant had 8 Wilfley concentrating tables in addition to Mineral Separation's sub-A flotation cells.
1932	The Great Depression.
1934	Coronet Phosphate Company stopped the hydraulicking of overburden; all overburden was now removed by dragline.
1938	Three companies were operating in hard rock field (hard rock production ceased in 1967), and six companies were operating in the land pebble district.
1939	World War II dislocated exports.
1940	Phosphate Recovery Corporation's Plant No. 2 operated with the double float process during March and April; obtained process and engineering data for design of Peace Valley recovery plant.
1942	Phosphate Recovery Corporation started up Peace Valley recovery plant and turned it over to International Minerals and Chemical Corporation.

Appendix C-1

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ZELLARS-WILLIAMS, INC.
U. S. BUREAU OF MINES
FLORIDA RESERVES STUDY

QUESTIONNAIRE I

Interviewer:_____ Date:_____

Personnel Interviewed:_____

I.   Deposit or Mine Name:_____

Additional Names, If Any:_____

II. County, State:_____

III. Type Deposit (Circle):   C   R   L

IV. Commodity (Circle): P_2O_5 F U_3O_8 HM

V.   Current Status:

0	Undetermined		4	Explored Prospect
1	Producer		5	Raw Prospect
2	Past Producer		6	Other
3	Explored Deposit			

VI. Type of Mineral Holdings (Up to Three):

0	Undetermined		5	Private Lease
1	Located Claim		6	Fee Ownership
2	Patented Claim		7	Minerals Only
3	Federal Lease		8	Other
4	State Lease		9	No Entry

Comments:_____

_____

VII. **Name of Owner Operator**   **Residence**   **% Owned**

VIII. Estimated Reserves:_____

IX. Mineability Screening Criteria Used to Determine Reserve:_____

_____

X.   Density Method Used:_____

XI. Other Information:_____

_____

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　　　　Page 1 of 3

ZELLARS-WILLIAMS, INC.
U. S. BUREAU OF MINES
FLORIDA RESERVES STUDY

QUESTIONNAIRE II

Interviewer:_____　　Date:_____

I. Deposit or Mine Name:_____

Additional Names, If Any:_____

II. Map Showing Property Ownership, Scale:_____

Indicate Deposit Center or Plant Site on Map, by Latitude, Longitude, or Section-

Township-Range:_____

Define Ore Body Limits on Map:_____

III. Primary Water Supply:_____

IV. Location to Nearest Power Source:_____

Existing or Proposed:_____

V. Primary Land Use:____Mining_____

Other:_____

VI. Environmental Land Restrictions, If Any:_____

_____

_____

VII. Mineable Acres:_____　　Total Acres:_____

VIII. Year of Discovery:_____

IX. Year of Significant Production:_____

X. Year Production Terminated or Projected for Termination:_____

XI. Prospect Density (Holes/Section):_____

XII. Ore In Place Density (Dry Weight):_____

XIII. Product Analysis: Range   Average

      Percent Pebble of Product   _____   _____

      Product BPL   _____   _____

      Product Insol   _____   _____

      Product I & A   _____   _____

      Product MgO   _____   _____

      Matrix Head BPL   _____   _____

XIV. Estimated Percent U_3O_8 of Product   _____   _____

XV. Estimated Percent Fluorine of Product   _____   _____

XVI. Ore Characteristics:

      Overburden Depth   _____   _____

      Ore Thickness   _____   _____

      Depth to Bedrock   _____   _____

      Percent Product Yield of Matrix
      (Dry Weight Basis)   _____   _____

XVII. Under what conditions and to what extent could this deposit be expanded within the present property limits?

_____

_____

_____

By Acquisition?_____

_____

XVIII. Mining Data:

      Production Capacity (Annual):   _____

      Digging Capacity (Yards Annually):   _____

      Pumping Capacity (Yards Annually):   _____

      Shifts Per Day: _____

      Pebble Recovery (Basis 100% Prospecting):   _____

      Concentrate Recovery (Basis 100% Prospecting):   _____

      Total Recovery (Basis 100% Prospecting):   _____

XIX. Transportation:

Percent Rock Product Sold: _____

Percent Consumed Internally: _____

Percent Product Exported: _____

    Port Location: _____

Percent Product Sold Domestically: _____

    Transport Points (Ports, Etc.) _____

    Destination (States) _____

XX. Cost Data:

Estimated Capital Cost of Facilities: _____

Estimated Cost Per Ton Wet Rock F.O.B. Mine: _____

Unit Production Costs (Variable): _____

Fixed Costs (O & A, Taxes, Depreciation, Etc.): _____

TOTAL COST _____

XXI. Other Comments or Information:

Appendix D. - Typical composition of Florida rock products[1]/

Product	Composition (percent)						
	77	75	73	72	70	68	66
BPL........	77.15	75.15	73.15	72.15	70.15	68.15	66.15
P_2O_5.......	35.31	34.39	33.48	33.02	32.11	31.19	30.27
CaO........	50.10	49.70	48.80	48.10	46.80	46.10	45.65
Fe_2O_3......	1.03	1.10	1.20	1.25	1.30	1.30	1.10
Al_2O_3......	1.02	1.00	1.10	1.15	1.30	1.40	1.40
I & A......	2.05	2.10	2.30	2.40	2.60	2.70	2.50
CO_2........	2.98	3.13	3.30	3.40	3.50	3.70	3.85
SO_3........	0.78	0.82	0.91	0.95	0.95	1.05	1.10
SiO_2.......	3.05	3.35	4.30	6.10	8.60	9.50	9.80
K_2O........	0.08	0.09	0.09	0.10	0.11	0.12	0.12
Na_2O.......	0.40	0.45	0.50	0.50	0.52	0.53	0.55
MgO........	0.23	0.28	0.34	0.38	0.45	0.51	0.57
F..........	3.87	3.82	3.75	3.70	3.65	3.60	3.50
Cl.........	0.005	0.006	0.007	0.007	0.008	0.009	0.009
Organics & comb. H_2O	2.20	2.45	2.50	2.55	2.60	2.75	2.85

[1]/ Unpublished data.

	Percentage composition of various grades						
	64% BPL	66% BPL	68% BPL	70% BPL	72% BPL	75% BPL	77% BPL
Phosphoric acid.....(P_2O_5)..	29.38	30.31	31.26	32.25	33.12	34.42	35.29
Oxide of lime.......(CaO)..	45.08	45.52	45.96	47.03	48.26	49.34	49.57
Oxide of iron.......(Fe_2O_3)..	1.61	1.54	1.44	1.37	1.29	1.20	0.88
Oxide of aluminum...(Al_2O_3)..	1.42	1.31	1.26	1.26	1.11	0.95	1.00
Carbonic acid.......(CO_2)..	4.38	4.02	3.67	3.25	3.20	3.12	2.99
Sulphuric acid......(SO_3)..	1.02	0.91	0.82	0.60	0.76	0.68	0.56
Sulphur (pyritic)...(S)..	0.08	0.06	0.07	0.08	0.04	0.03	0.03
Silica..............(SiO_2)..	10.85	10.25	9.55	8.65	6.10	4.21	3.95
Oxide of potassium..(K_2O)..	0.165	0.157	0.145	0.135	0.126	0.120	0.09
Oxide of sodium.....(Na_2O)..	0.253	0.243	0.221	0.205	0.243	0.216	0.186
Oxide of magnesium..(MgO)..	0.58	0.52	0.37	0.20	0.28	0.17	0.22
Oxide of manganese..(MnO)..	0.053	0.047	0.019	0.029	0.038	0.024	0.014
Oxide of titanium...(TiO_2)..	0.069	0.074	0.092	0.078	0.236	0.153	0.149
Oxide of arsenic....(As_2O_3)..	0.011	0.009	0.0118	0.0124	0.0114	0.0155	0.0082
Oxide of chromium...(Cr_2O_3)..	0.206	0.0191	0.0171	0.0182	0.0146	0.0101	0.0082
Oxide of vanadium...(V_2O_3)..	0.0073	0.0064	0.0086	0.012	0.0091	0.0069	0.0089
Fluorine............(F)..	3.54	3.62	3.70	3.80	3.81	3.84	3.87
Chlorine............(Cl)..	0.011	0.011	0.012	0.010	0.009	0.008	0.006
Organic matter..............	0.80	0.75	0.75	0.70	0.65	0.60	0.60
Combined water......(H_2O)..	2.35	2.28	2.17	1.94	2.17	2.40	2.23
Total	101.8299	101.6565	101.5465	101.8296	101.2771	101.5135	101.6603
Less oxygen equivalent of fluorine	1.49	1.52	1.56	1.60	1.60	1.62	1.63
CORRECTED TOTAL	100.1899	100.1365	99.9865	100.0296	99.8771	99.8935	100.0303

[1]/ Unpublished data.

Appendix F. - General informational soruces for Florida phosphate study

Information	Sources
Deposit Identification-Ownership; Resources - Grade; Exploration Methods; Deposit Characteristics; Size and Quality of Resource	Owner-operators, county platbooks, drill core data (North and East Florida), consultants, company exploration reports, government agencies, general literature.
Location - Elevation..................	Owner-operators, county maps, USGS topographic maps, private company maps, county record books.
Climatology...........................	Local weather stations.
Soil Information......................	Soil surveys by U. S. Soil Conservation Service.
Vegetation - Land Use.................	USGS Land Use and Land Cover Maps, Regional Planning Council Land Use Maps.
Environmental Sensitivity.............	Land use maps, interviews with state and local agencies, EPA Regional EIS symposium and scenarios, press releases, Southwest Florida Water Management District, Development of Regional Impact studies.
Geologic Information; Mining and Milling Capacity; Equipment; Operational Description	General literature, questionnaire responses, Development of Regional Impact studies.
Commodity Information.................	P_2O_5 gangue minerals derivation from cited sources, uranium, fluorine estimated from general literature.
Transportation; Operational........... Integration	Cited sources, estimates based on internal chemical capacity.
Cost Information......................	Cost cases and models prepared (separate reports), information directly offered or estimated in unique cases.

Appendix G. - Florida-North Carolina phosphate rock[1]

Sold or used by producers, by type of rock, 1888-1970
(thousands of long tons and thousands of dollars)

Year	Land Pebble Qty.	Val.	Hardrock Qty.	Val.	Softrock Qty.	Val.	River Pebble Qty.	Val.	Total Qty.	Val.[2]
1888	-	-	-	-	-	-	-	-	3[3]	20
1889	-	-	-	-	-	-	-	-	8[3]	40
1890	-	-	-[4]	-[4]	-[4]	-[4]	-	-	46[3]	330
1891	58	-					54	-	112	700
1892	22	111	156	859	7	32	102	-	287	1,410
1893	86	359	216	1,118	14	64	123	437	438	1,970
1894	98	297	326	979	-	-	102	391	528	1,660
1895	181	594	307	1,302	7	32	73	185	568	2,110
1896	98	176	297	1,067	-	2	100	300	495	1,540
1897	92	181	360	1,064	2	5	98	244	522	1,490
1898	155	294	367	1,396	0	0	79	158	601	1,840
1899	177	515	460	2,119	0	0	89	169	726	2,800
1900	221	613	425	2,229	0	0	60	141	706	2,980
1901	247	661	457	2,393	0	0	47	106	752	3,150
1902	351	811	429	1,744	0	0	5	10	785	2,560
1903	391	885	413	1,988	0	0	56	113	860	2,980
1904	461	1,103	531	2,672	0	0	81	199	1,073	3,970
1905	528	1,045	578	2,994	0	0	88	213	1,194	4,250
1906	675	2,029	587	3,440	0	0	41	116	1,304	5,580
1907	675	2,376	646	4,065	0	0	36	136	1,357	6,570
1908	1,085	3,885	596	4,566	0	0	11	33	1,692	8,480
1909	1,266	4,515	513	4,026	0	0	0	0	1,779	8,540
1910	1,629	5,569	438	3,051	0	0	0	0	2,067	8,640
1911	1,993	6,712	443	2,761	0	0	0	0	2,436	9,470
1912	1,913	6,168	493	3,293	0	0	0	0	2,407	9,460
1913	2,055	6,576	490	2,987	0	0	0	0	2,545	9,560
1914	1,829	5,442	310	1,012	0	0	0	0	2,139	7,350
1915	1,308	3,496	50	265	0	0	0	0	1,359	3,760
1916	1,469	3,874	47	296	0	0	0	0	1,516	4,170
1917	2,004	5,305	18	159	0	0	0	0	2,022	5,460
1918	1,997	5,556	62	377	8	147	0	0	2,067	6,090
1919	1,360	5,149	285	2,452	14	196	0	0	1,660	7,790
1920	2,955	14,749	400	4,525	13	190	0	0	3,369	19,460
1921	1,600	8,605	176	1,807	4	20	0	0	1,780	10,430
1922	1,870	4,035	188	1,308	-	3	0	0	2,058	3,340
1923	2,348	4,988	199	1,072	0	0	0	0	2,548	9,050
1924	2,389	7,388	143	629	0	0	0	0	2,432	8,010
1925	2,758	8,081	172	708	0	0	0	0	2,930	8,780
1926	2,592	8,218	116	465	0	0	0	0	2,708	8,680

See footnotes at end of table.

Year	Land Pebble		Hardrock		Softrock		River Pebble		Total	
	Qty.	Val.	Qty.	Val.	Qty.	Val.	Qty.	Val.	Qty.	Val.[2]
1927	2,506	8,121	131	525	0	0	0	0	2,637	8,640
1928	2,787	9,040	96	384			0	0	2,833	9,420
1929	3,016	9,634	72	267	0	0	0	0	3,088	9,000
1930	3,166	10,273	82	417	0	0	0	0	3,248	10,790
1931	1,990	6,756	57	380	13	65	0	0	2,061	7,200
1932	1,402	4,490	57	162	10	24	0	0	1,470	4,780
1933	2,067	6,031	52	347	16	48	0	0	2,136	6,420
1934	2,249	7,466	91	523	28	86	0	0	2,359	8,080
1935	2,270	7,736	116	500	36	125	0	0	2,423	8,380
1936	2,454	7,846	139	579	32	103	0	0	2,625	8,530
1937	2,872	8,600	64	342	50	200	0	0	2,997	9,140
1938	2,528	7,994	125	601	53	178	0	0	2,707	8,770
1939	2,547	7,353	89	411	42	128	0	0	2,679	7,890
1940	2,781	7,538	22	100	42	102	0	0	3,845	10,230
1941	3,280	9.890	28	211	48	132	0	0	3,365	9,380
1942	2,894	8,826	70	396	48	155	0	0	3,012	12,090
1943	3,483	11,633	34	201	71	255	0	0	3,538	13,530
1944	3,670	13,136	22	138	60	239	0	0	3,752	16,300
1945	4,103	15,579	63	426	71	293	0	0	4,238	18,770
1946	4,807	19,867	100	762	97	387	0	0	5,005	21,020
1947	6,314	31,976	79	618	89	326	0	0	6,482	32,920
1948	6,422	37,070	48	368	69	294	0	0	6,539	37,730
1949	6,715	37,340	24	173	77	345	0	0	6,816	37,860
1950	7,933	44,431	71	538	81	408	0	0	8,086	45,380
1951	8,329	49,185	76	582	92	495	0	0	8,497	50,260
1952	8,624	50,483	81	625	76	433	0	0	8,781	51,540
1953	9,009	54,498	81	643	76	470	0	0	9,167	55,610
1954	9,566	58,890	74	585	90	554	0	0	9,730	60,030
1955	9,401	47,974	92	739	72	466	0	0	9,565	59,180
1956	10,366	64,354	103	873	59	376	0	0	10,528	65,600
1957	10,508	66,863	80	682	56	401	0	0	10,644	67,950
1958	10,466	66,309	76	638	51	405	0	0	10,573	67,350
1959	11,628	71,771	76	649	56	443	0	0	11,760	62,860
1960	12,132	80,905	74	639	45	372	0	0	12,251	81,920
1961	12,667	88,395	73	672	39	303	0	0	12,799	89,370
1962	13,624	93,669	70	659	33	275	0	0	13,727	94,600
1963	14,377	100,749	76	723	33	269	0	0	14,486	101,740
1964	16,252	115,513	77	747	28	225	0	0	16,357	116,490
1965	19,096	138,744	69	684	28	221	0	0	19,193	139,650

See footnotes at end of table.

	Land Pebble		Hardrock		Softrock		River Pebble		Total	
Year	Qty.	Val.	Qty.	Val.	Qty.	Val.	Qty.	Val.	Qty.	Val.2/
1966 5/	25,037	184,075	44	437	40	293	0	0	25,121	184,370
1967	26,611	193,283	0	0	32	266	0	0	26,643	193,550
1968	26,401	173,190	0	0	27	224	0	0	26,428	173,410
1969	25,263	155,197	0	0	27	221	0	0	25,290	155,420
1970	28,300	152,200	0	0	27	220 6/	0	0	28,520	152,420
1971	28,706	167,753	0	0	18	141	0	0	28,724	167,894
1972	30,465	173,910	0	0	19	121	0	0	30,484	174,031
1973	30,738	191,654	0	0	20	154	0	0	30,758	191,808
1974	33,018	408,979	0	0	37	571	0	0	33,055	409,550
1975	36,338	1,000,352	0	0	25	503	0	0	36,363	1,000,855
1976	37,096	867,902	0	0	29	580	0	0	37,125	867,672
1977	39,936	718,393	0	0	25	504	0	0	39,961	718,897

1/ Tons of land pebble include both Northern and Central Florida phosphate districts, and North Carolina. This combination is for the purpose of protecting confidential production information for each of the single producers in the Northern Florida phosphate district and North Carolina.

2/ All values rounded.

3/ Includes all types of phosphate.

4/ Included with land pebble.

5/ Includes North Carolina production.

6/ Estimated.