CIRC. 930-C

U.S. GEOLOGICAL SURVEY CIRCULAR 930-C

International Strategic Minerals Inventory Summary Report—Phosphate

Prepared as a cooperative effort among earth-science and mineral-resource agencies of Australia, Canada, the Federal Republic of Germany, the Republic of South Africa, and the United States of America

Major geologic age units

Age			Million years before present
Holocene	QUATERNARY	CENOZOIC	0.1
Pleistocene	QUATERNARY	CENOZOIC	2
Pliocene	TERTIARY	CENOZOIC	5
Miocene	TERTIARY	CENOZOIC	24
Oligocene	TERTIARY	CENOZOIC	38
Eocene	TERTIARY	CENOZOIC	55
Paleocene	TERTIARY	CENOZOIC	63
Late Cretaceous	Cretaceous	MESOZOIC	96
Early Cretaceous	Cretaceous	MESOZOIC	138
Jurassic		MESOZOIC	205
Triassic		MESOZOIC	~240
Permian		PALEOZOIC	290
Pennsylvanian	Carboniferous	PALEOZOIC	~330
Mississippian	Carboniferous	PALEOZOIC	360
Devonian		PALEOZOIC	410
Silurian		PALEOZOIC	435
Ordovician		PALEOZOIC	500
Cambrian		PALEOZOIC	~570
PRECAMBRIAN	Late Proterozoic	PROTEROZOIC	900
PRECAMBRIAN	Middle Proterozoic	PROTEROZOIC	1600
PRECAMBRIAN	Early Proterozoic	PROTEROZOIC	2500
PRECAMBRIAN		ARCHEAN	

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By Ulrich H. Krauss, Henning G. Saam,
and Helmut W. Schmidt

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FOREWORD

Earth-science and mineral-resource agencies from several countries started the International Strategic Minerals Inventory in order to gather cooperatively information about major sources of strategic mineral raw materials. This circular summarizes inventory information about major deposits of phosphate, one of the mineral commodities selected for the prototype phase of the inventory.

This report was prepared by Ulrich H. Krauss, Henning G. Saam, and Helmut W. Schmidt of the Federal Institute for Geosciences and Natural Resources (BGR) of the Federal Republic of Germany and was edited by David Slater of the British Geological Survey (BGS). Phosphate inventory information was compiled by G.S. Barry, Canadian Department of Energy, Mines and Resources (EMR), Mineral Policy Sector (MPS); James B. Cathcart, U.S. Geological Survey (USGS); R.L. Christie, EMR, Geological Survey of Canada; Aert Driessen, Australian Bureau of Mineral Resources, Geology and Geophysics; Ian Goldberg, South African Department of Mineral and Energy Affairs (MEA), Minerals Bureau; Erik C.I. Hammerbeck, MEA, Geological Survey; Ursala Hofmann, BGR; Ulrich H. Krauss (chief compiler), BGR; Henning G. Saam, BGR; and A.G. Sozanski, EMR, MPS.

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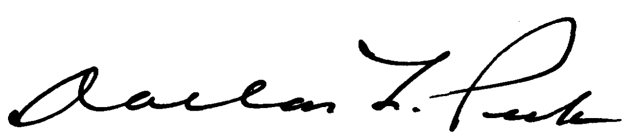

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INTERNATIONAL STRATEGIC MINERALS INVENTORY SUMMARY REPORT

PHOSPHATE

By Ulrich H. Krauss, Henning G. Saam, and Helmut W. Schmidt[1]

ABSTRACT

Major world resources of phosphate, a strategic mineral commodity, are described in this summary report of information in the International Strategic Minerals Inventory (ISMI). ISMI is a cooperative data-collection effort of earth-science and mineral-resource agencies in Australia, Canada, the Federal Republic of Germany, the Republic of South Africa, and the United States of America. This report, designed to be of benefit to policy analysts, contains two parts. Part I presents an overview of the resources and potential supply of phosphate on the basis of inventory information. Part II contains a table of some of the geologic information and mineral-resource and production data that were collected by ISMI participants.

PART I—OVERVIEW

INTRODUCTION

The reliability of future supplies of so-called strategic minerals is of concern to many nations. This widespread concern has led to duplication of effort in the gathering of information on the world's major sources of strategic mineral materials. With the aim of pooling such information, a cooperative program named International Strategic Minerals Inventory (ISMI) was started in 1981 by officials of the governments of the U.S.A., Canada, and the Federal Republic of Germany. It was subsequently joined by the Republic of South Africa and Australia. The United Kingdom will participate in future ISMI resource studies.

The objective of ISMI reports is to make publicly available, in convenient form, nonproprietary data and characteristics of major deposits of strategic mineral commodities for policy considerations in regard to short-term, medium-term, and long-term world supply. This report provides a summary statement of the data compiled and an overview of the supply aspects of phosphate in a format designed to be of benefit to policy analysts.

The term "strategic minerals" is imprecise. It generally refers to mineral ore and derivative products that come largely or entirely from foreign sources, that are difficult to replace, and that are important to a nation's economy, in particular to its defense industry. Usually, the term implies a nation's perception of vulnerability to supply disruptions, and of a need to safeguard its industries from the repercussions of a loss of supplies.

Because a mineral that is strategic to one country may not be strategic to another, no one list of strategic minerals can be prepared. The ISMI Working Group decided to commence with chromium, manganese, nickel, and phosphate.

The information used was the best at hand in various agencies of the participating countries that contributed to the preparation of this report. Those agencies were the Bureau of Mines and the Geological Survey of the U.S. Department of the Interior; the Geological Survey and the Mineral Policy Sector of the Canadian Department of Energy, Mines and Resources; the Federal Institute for Geosciences and Natural Resources of the Federal Republic of Germany; the Geological Survey and the Minerals Bureau of the Department of Mineral and Energy Affairs of South

[1]Authors are with the Federal Institute for Geosciences and Natural Resources (BGR) of the Federal Republic of Germany.

Africa; and the Bureau of Mineral Resources, Geology and Geophysics of the Australian Department of Resources and Energy.

Deposits (or districts) are selected for the inventory on the basis of their present or expected future contribution to world supply. Records for all deposits compiled by ISMI participants meet this general "major deposit" criterion and are included in the inventory.[2]

The ISMI record collection and this report on phosphate have adopted the international classification system for mineral resources recommended by the United Nations Group of Experts on Definitions and Terminology for Mineral Resources (Schanz, 1980). The terms, definitions, and resource categories of this system were established in 1979 to facilitate international exchange of mineral-resource data; the Group of Experts sought a system that would be compatible with the several systems already in use in several countries.

Figure 1 shows the U.N. resource classification used in this report. The term "reserves," which many would consider to be equivalent to r1E or R1E, has been interpreted inconsistently and thus has been deliberately avoided in the U.N. classification. Category R3, undiscovered deposits, is not dealt with in this report.

PHOSPHATE—BACKGROUND AND TERMINOLOGY

Phosphorus is an important component of the cell tissue of plants and animals; it is necessary for the structure, growth, and propagation of living organisms. Phosphorus enters the organic food chain from the soil through the roots of plants. The human body contains about 1 percent by weight phosphorus, most of it in the bones and teeth. The human body requires a daily intake of 0.6–0.7 g of phosphorus in the appropriate chemical form.

Phosphate ores are mined principally for the purpose of making phosphate fertilizers. Phosphorus is an essential plant nutrient which is scarce in some soils or may become depleted even in richer soils by continual, particularly intensive, cultivation.

Phosphorus is also important, in the form of special compounds, for various industrial applications, for example, in the production of detergents, animal feed supplements, food preservatives, substances for water treatment, anticorrosion agents, cosmetics, and fungicides. Minor amounts of phosphorus are used by the metallurgy and ceramics industries.

The proportion of phosphorus (P) in the Earth's crust averages 0.10 to 0.12 percent so that the element is 11th in order of abundance. Phosphate deposits currently being mined have contents of about 4 percent (for example, deposits in Brazil and Mexico) to nearly 38 percent phosphorus pentoxide (P_2O_5). If a phosphate deposit is to be worth mining, therefore, its phosphorus content must be at least 15 times, and usually 80 to 150 times, higher than the average amount contained in the crust.

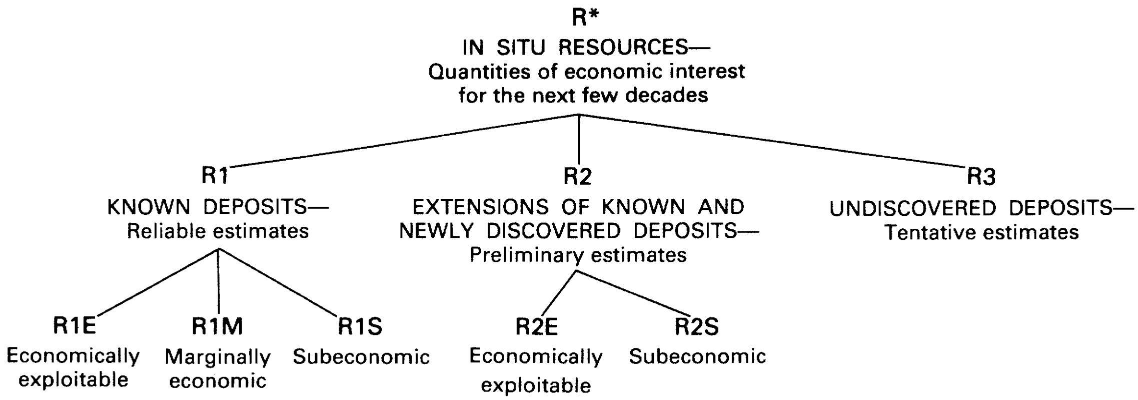
Workable phosphate deposits are commonly formed by concentration processes in the food chain; by precipitation in regions of upwelling, cold, nutrient-rich oceanic water from great depths (marine sedimentary phosphate deposits); by differentiation of minerals within partially molten magmas (igneous phosphate deposits); or by enrichment in residual material due to weathering of phosphate-containing subjacent rocks.

Only a few of the 200 known minerals containing more than 1 percent P_2O_5 are used to produce phosphorus or phosphate compounds. The various types of apatite are by far the most important. Less so are the aluminum- and iron-bearing phosphate hydrates which occur primarily as residual weathering products above phosphate hydrates which occur primarily as residual weathering products above phosphate deposits. Apatite occurs in nearly all igneous, metamorphic, and sedimentary rocks as an accessory mineral. It is estimated that about 95 percent of the phosphorus in the Earth's crust is bound in the various forms of apatite. Table 1 shows the chemical composition of apatites from phosphate deposits in several countries.

Conventions in the nomenclature for phosphate ores and concentrates vary among countries. To avoid confusion, the following terms are used in this report:

Phosphate ore. Phosphate-bearing rock which is being mined to produce phosphate concentrate, or which is considered likely to be economically workable. The P_2O_5 content may be as low as 4 percent but is usually very much higher.

[2]No information is provided on deposits that were once significant but whose resources are now considered to have been depleted.



*The capital "R" denotes resources *in situ*; a lower case "r" expresses the corresponding *recoverable* resources for each category and subcategory. Thus, r1E is the recoverable equivalent of R1E. This report deals only with R1 and R2, not with R3.

FIGURE 1.—United Nations resource categories used in this report (modified from Schanz, 1980, p. 313).

TABLE 1.—*Chemical composition of naturally occurring apatites, in percent*

[Tunisia deposit percentages calculated from data in Chaabani (1978); percentages for all other deposits calculated from data in McClellan and Lehr (1969)]

	CaO	MgO	Na_2O	P_2O_5	CO_2	F_2
Igneous deposits						
Kola, Soviet Union	55.13	0.42	0.38	40.30	0.42	3.35
Quebec, Canada	55.16	.20	.25	40.77	.20	3.42
Sweden	55.17	.26	.14	39.88	.10	4.44
Sedimentary deposits						
Morocco	54.1	0.81	0.28	38.2	2.32	4.33
Tunisia	54.7	.46	.26	34.8	5.61	4.11
Florida, U.S.A.	55.1	.32	.65	35.8	3.90	4.22
Senegal	54.70	.31	.18	39.09	1.72	4.00
Australia	54.03	.83	.14	40.73	.31	3.96

Phosphate concentrate. Often referred to commercially as "phosphate rock". It is produced from phosphate ore by beneficiation. Phosphate concentrates have contents of 29 to 40 percent P_2O_5.

Phosphate ores and concentrates from igneous deposits are also termed apatite ores and apatite concentrates respectively. Marine sedimentary deposits of phosphate ore, from which phosphorite concentrates are produced, are also called phosphorite ores.

Apatite ore. The main phosphate mineral is apatite, although other phosphate minerals such as crandallite can occur in weathering products. Other minerals in some ores are used in the production of by- or co-products—for example, iron minerals and uranium.

Phosphorite ore. The main phosphate mineral is apatite (usually francolite); more infrequently, in leached ores, phosphate minerals such as crandallite, wavellite, augelite, and others also occur.

The phosphorus content of ores and concentrates may be presented in one of several different ways: in weight percent phosphorus or P_2O_5 or as percent of BPL, TCP, or TPL. These last three expressions, respectively bone phosphate of lime, tricalcium phosphate, and triphosphate of lime, have the same meaning and refer to the content of tricalcium phosphate, $CA_3(PO_4)_2$, which contains 45.76 percent P_2O_5, or 19.97 percent phosphorus. The conversion factors in table 2 can be used to convert from one expression to another.

TABLE 2.—*Conversion factors for phosphorus content, in percent*

[BPL=bone phosphate of lime, TCP=tricalcium phosphate, and TPL=triphosphate of lime]

	P	P_2O_5	BPL
1.0% P	1	2.2914	5.0072
1.0% P_2O_5	0.4364	1	2.1852
1.0% BPL or TCP or TPL	.1997	.4576	1

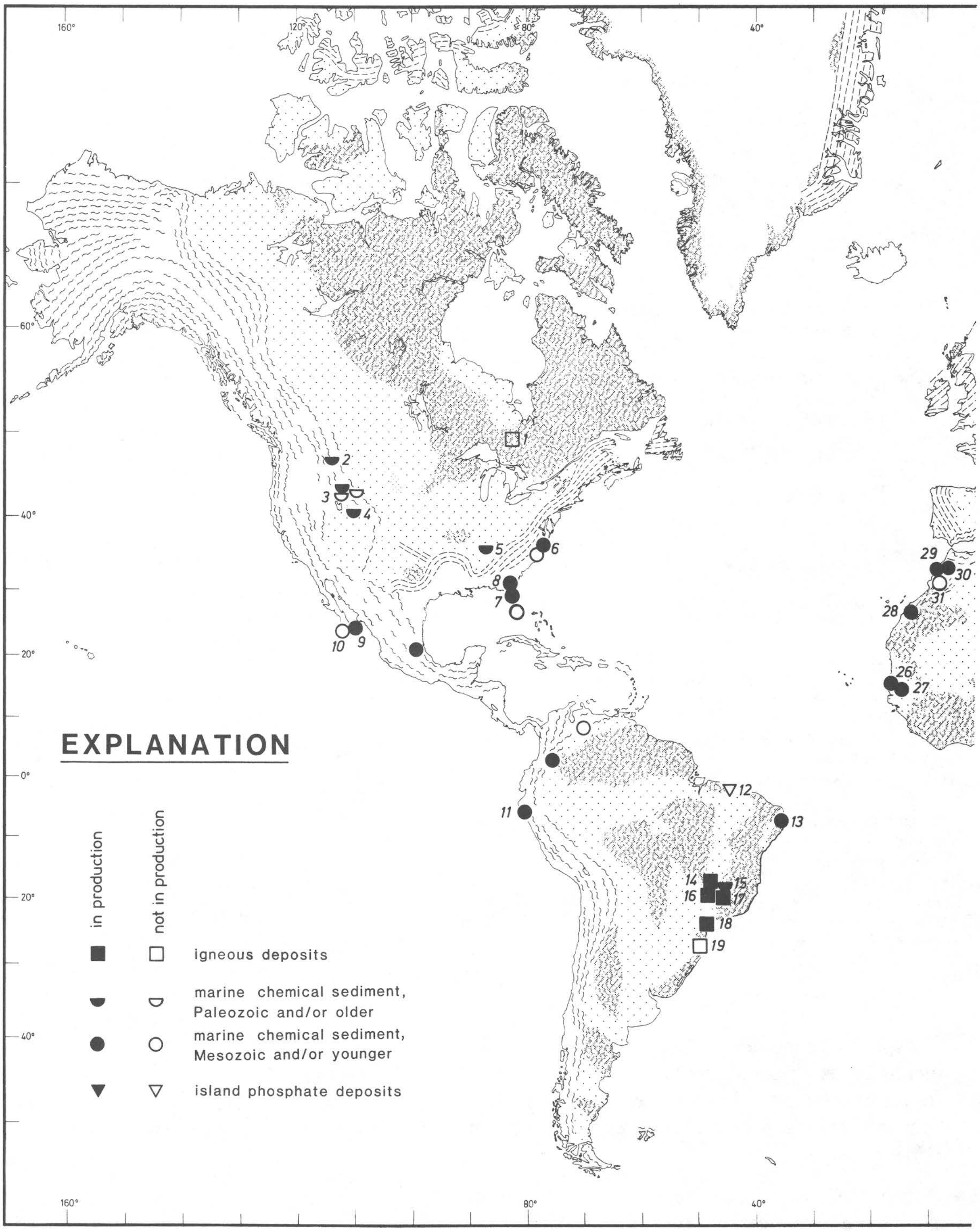
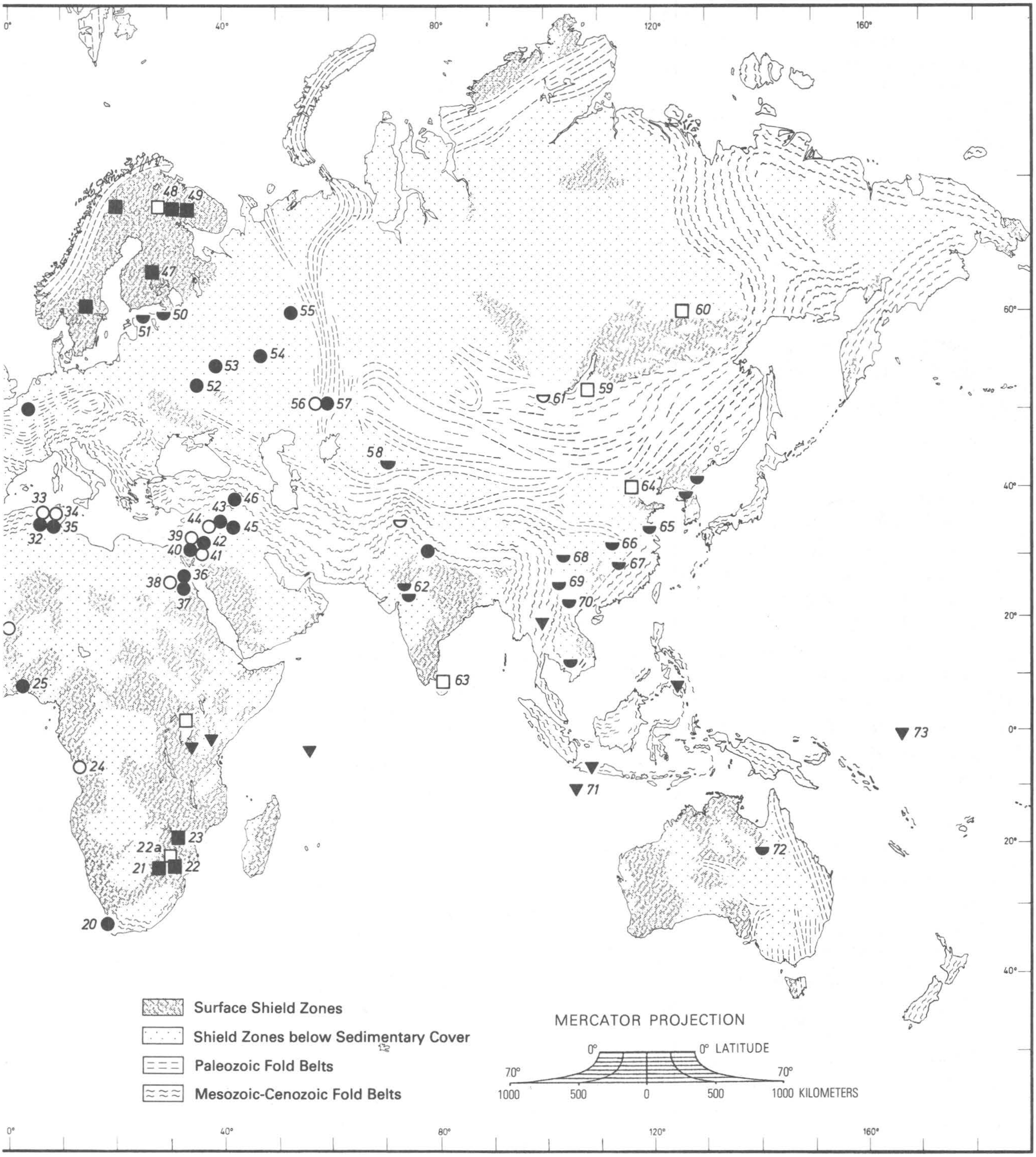


FIGURE 2.—Location, deposit type, and production status of major phosphate deposits and districts in the world. The numbers

DISTRIBUTION OF PHOSPHATE DEPOSITS AND DISTRICTS

The world map in figure 2 shows the locations of the more important phosphate deposits and districts. Of the 180 deposits or mining properties that are producing or that will probably go into production, 140 have been included in this compilation. These are considered to account for more than 95



correspond to numbers listed for deposits/districts in table 12 of Part II. Deposits without numbers are not included in the inventory.

percent of the total production and resources. A major share of economic phosphate deposits occurs in a few countries. In certain large areas such as South America, Australia, and New Zealand; in highly populated areas such as India, Indonesia, and Malaysia; and in areas of especially high use of phosphate such as western Europe, few deposits are known. The concentration of phosphate supply and resources within a relatively few areas in the world is thus far greater than would be assumed from the large number of deposits shown in figure 2.

Phosphate concentrates are produced from marine sedimentary, igneous, and island phosphate deposits.

Marine sedimentary phosphorite deposits. The extensive deposits of Florida, west and north Africa (Algeria, Morocco, Senegal, Togo, and Tunisia), and the Middle East (for example, Egypt, Israel, and Jordan) belong to this type. Marine sedimentary phosphorite deposits are found in stable shelf regions as accumulations in depressions and relatively closed basins such as the Gafsa basin in Tunisia. The phosphate ore (phosphorite) occurs in seams within characteristic, relatively thin, marine sediment sequences (phosphate facies sequences consisting of bituminous marl, phosphorite, chert, argillite, and limestone), and results from chemical and biological precipitation of phosphate in areas of upwelling, phosphate-rich marine waters.

The most important mineral in phosphorite ores is francolite (a variety of apatite). A certain amount of phosphorus is in the form of fossil bones and teeth, which are plentiful in some phosphorite occurrences. The accompanying minerals in phosphorite are primarily quartz, silica, carbonates, and clay. The P_2O_5 content of phosphorite ores is generally between 18 and 33 percent.

Secondary, reworked deposits of phosphorite, such as those in Florida, can have significantly lower concentrations. In some localities such as Senegal and Morocco, a residual phosphate enrichment takes place in near-surface phosphorites as a result of tropical weathering.

The concentrates produced from phosphorite ores generally have a P_2O_5 content between 29 and 37 percent. The economic resources of individual deposits range from 30 million to 1 billion metric tons and, in exceptional cases (Oulad Abdoun, Morocco), to more than 5 billion metric tons.

Igneous deposits. Examples of this deposit type are the Khibiny deposit, Soviet Union; Phalaborwa, South Africa; and Araxa and Tapira, Brazil.

Apatite is an accessory mineral in nearly all igneous rocks, but reaches commercially interesting concentrations only in certain deposits associated with alkaline igneous rock complexes, at least 280 of which are known to occur in various parts of the world. The phosphate production of several countries (for example, the Soviet Union, South Africa, Brazil, Finland, and Zimbabwe) is derived primarily or entirely from such igneous deposits. Deposits of this type that are of possible interest for future phosphate production are found in Canada and several African countries (Uganda, Tanzania, Zambia, Zaire, and Malawi).

The P_2O_5 content of igneous apatite ores (4 to 10 percent, seldom as high as 20 percent) is considerably less than that of marine sedimentary phosphorite ores, but igneous ores can be beneficiated to produce high-grade concentrates (36–42 percent P_2O_5) at relatively low cost. A thick cover of weathered material in which apatite is residually enriched (up to 20 percent P_2O_5) may locally overlie some igneous apatite deposits in tropical regions. Large igneous phosphate deposits have economic resources ranging individually up to as much as 800 million metric tons of contained P_2O_5.

Island phosphate deposits. The deposits on Nauru, Christmas Island, and other islands in the Indian and Pacific Oceans belong to this type, as do the now exhausted Curacao deposits and occurrences not being exploited at present such as those at Trauira, Brazil, and Minjingu-Arusha, Tanzania. Island phosphate deposits have traditionally been regarded as the result of the accumulation of guano, mainly near nesting areas of sea birds. The fresh excrement is rich in nitrogen compounds and also contains about 4 percent P_2O_5. Completely leached guano deposits can contain as much as 32 percent P_2O_5; this phosphate is in the form of calcium phosphate and calcium hydrogen phosphate (monetite and whitlockite). During the leaching of guano accumulations, phosphate ions are washed into the underlying rocks where replacement minerals and phosphate precipitates are formed. More recent research has indicated that the island phosphate deposits may be of inorganic origin (Bourrouilh-LeJan, 1980).

The phosphate ores from island deposits are very high-grade; the concentrates produced from them contain 36 to 38 percent P_2O_5. Owing to their low fluorine contents, island phosphate ores are suitable for use as an additive to animal fodder. Some of the phosphate ores with high aluminum contents, such as the C-grade[3] ores of Christmas Island, are not economically exploitable at present.

The importance of island deposits for the production of phosphate will continue to decrease. According to present knowledge, discoveries of large deposits of this type cannot be expected in the future. The economic resources of individual deposits being mined at present amount to several tens of millions of tons of ore.

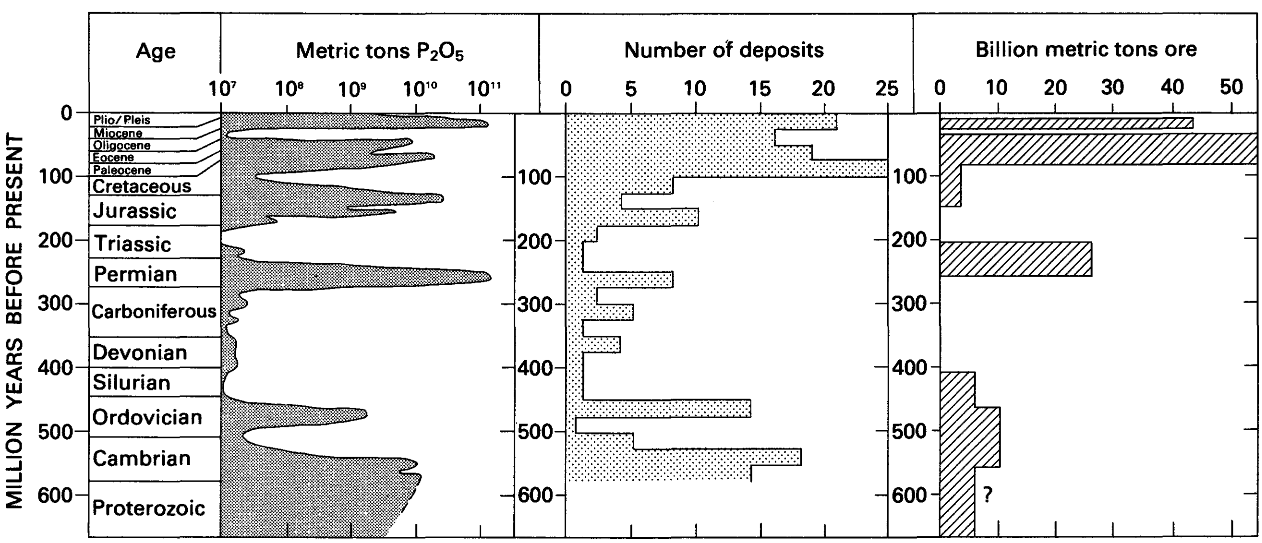
A certain relationship between the distribution of the phosphate deposits and the geotectonic environment can be recognized in figure 2. Phosphate deposits are located primarily at the margins of the old shield areas or in consolidated, old folded mountain areas covered with younger sediments. The distribution of phosphate deposits is also determined by other geologic factors. The conditions favorable to the formation of phosphate deposits were most intensively developed in certain geological periods, as can be seen in figure 3. This preferential distribution is demonstrated for deposits and districts in the inventory in table 3.

TABLE 3.—*Number of the world's major phosphate deposits and districts by age of formation*

Geologic age[1]	Number of deposits: Sedimentary	Number of deposits: Igneous
Post-Pleiocene	3	---
Oligocene through Pliocene	31	---
Late Cretaceous through Eocene	47	---
Jurassic through Early Cretaceous	4	6
Carboniferous through Permian	19	1
Ordovician through Devonian	3	3
Precambrian and Cambrian	22	11
Total[2]	129	21

[1]No major phosphate deposits of Triassic age are known.
[2]Total includes residual deposits derived from subjacent bedrock.

Most of the phosphorite deposits were formed in areas near the equator. Some of the Jurassic and possibly Cambrian occurrences were deposited in the temperate zone (Cook and McElhinny, 1979). The paleogeographic relief of the sea floor (basin structures, depressions) was also of significance for the formation of phosphorite deposits. Phosphorite deposits occur typically in certain types of sediment sequences (for example, bituminous schist, chert, marl, and evaporites) that indicate special chemical, physical, climatic, and biological



Note: Data for tons of P_2O_5 in some cases include more resource classes than do data for tons of ore so that calculation of grades using these two variables is not appropriate

FIGURE 3.—Estimated stratigraphic distribution of world phosphate deposits (modified from Cook and McElhinny, 1979, p. 316, and Slansky, 1980, p. 56).

[3]Christmas Island phosphates are classified as A-grade, B-grade, and C-grade. The C-grade rock is an aluminum- and phosphate-rich subsoil derived by weathering and phosphatization of carbonate and volcanic rocks. The A-grade ore is principally fine-grained apatite overlying limestone and is the highest grade of ore on the island. The B-grade material is a mixture of A-grade and C-grade material and forms a transitional zone between them (Mew, 1980, p. 195–196).

conditions necessary for the formation of phosphate deposits. Summary papers with extensive references to the literature have been published by Kazakov (1937), McKelvey (1967), Slansky (1980), Bentor (1980), and others.

MINING, PROCESSING, AND END USE

Those phosphate mines that recently began production have identified, economic resources (R1E) of at least 20 to 30 million metric tons of ore.[4] Many of the deposits being mined today have demonstrated resources of 100 to 500 million metric tons of ore. Several very large deposits contain from about 800 million to several billion tons of ore. The grades of ores being mined for the production of concentrates are between 4 and 36 percent P_2O_5. The average grade necessary for profitable mining of a particular deposit depends on the physical and chemical properties of the minerals in the ore and also on whether other materials, in addition to phosphate, can be economically recovered (for example, rare earths and zircon). Other factors, such as the proximity of the deposit to consumers and to seaports, are of major significance. The following generalizations can be made with reference to grades of phosphate mined:

- Marine sedimentary phosphorite, which contains phosphorus in very fine-grained apatite, requires a P_2O_5 content of at least 20 percent.
- Secondary, reworked phosphorite deposits (for example, those in Florida) may be profitably mined at much lower contents (down to about 7 percent P_2O_5).
- The P_2O_5 content of the igneous apatite deposits (in alkali rock/carbonatite complexes) being mined at present ranges between 4 and 17 percent, usually 7 to 10 percent. In tropical areas, the residual soils overlying such deposits may be enriched in phosphorus to as much as 15 or even 20 percent P_2O_5.

About 87 percent of world phosphate ore production is derived from open-pit mines. Waste rock, including overburden and country rock, amounts to between 2 and 7 metric tons per ton of ore mined in open pits. When this figure begins to exceed 6 or 7 metric tons, conversion to underground mining must be considered. Run-of-mine ore production capacity of existing mines is 0.6 to 1.0 million metric tons annually for small operations, between 1 and 8 million metric tons annually for medium-sized operations, and over 8 million (up to 25 million) metric tons annually for large mines. Most of the processing plants near phosphate mines have annual capacities between 0.1 and 10 million metric tons of concentrate, usually between 0.5 and 5 million metric tons. Plants with large capacities include those near the Sidi-Daoui mine in Morocco (10 million metric tons of concentrate annually, but with a relatively simple processing flow scheme) and near the mines in the Khibiny Complex in the Soviet Union.

The purpose of processing is to produce a saleable concentrate from the mined ore. Even very high-grade ores (such as those from Morocco) are at least broken, sieved, and milled before being sold. Limestone and siliceous clumps are removed during this relatively simple treatment (15–25 percent waste), resulting in a slight enrichment of the concentrate relative to the ore of several percent BPL. Phosphate recovery is from 80 to 90 percent. Phosphorite ores containing quartz and clay are usually subjected to washing and cycloning as in Jordan. The phosphate ores of Florida are washed and then subjected to flotation. Phosphate recovery is usually between 60 and 70 percent; for ores that are difficult to process, such as those from west African deposits, the yield can be as little as 35 percent. In general, 3 to 6.5 metric tons of crude ore are needed to produce 1 ton of concentrate. Igneous apatite ores are almost always subjected to flotation; yields are between 78 and 85 percent. Concentrates produced from phosphorite ores grade from 29 to 37 percent P_2O_5; those from igneous apatite ores grade from 36 to 42 percent.

Phosphate ores and concentrates produced around the world are used for agricultural purposes (86–88 percent) and as industrial raw materials (12–14 percent). Agricultural uses include the production of chemical fertilizers (76–78 percent), additives to animal fodder (about 6 percent), and direct application as a fertilizer (about 4 percent). Industrial uses include additives for detergents (7–8 percent) and applications to phosphorus-containing products and intermediates of the chemical industry, pharmaceutical

[4] Small-size phosphate deposits have economic resources up to 10 million tons of P_2O_5; medium-size deposits contain about 10 to 100 million tons; deposits with 100 million tons or more are regarded as large.

products, industrial detergents, anticorrosion agents, and pyrotechnic products (5–6 percent).

The main technological methods for further processing and refining phosphate concentrates can be grouped according to application:

- Phosphate ore used by the fertilizer industry is processed almost exclusively by the wet acidulation process using sulfuric or phosphoric acids.

- Elemental phosphorus used by industry has traditionally been produced almost exclusively by thermal reduction of phospohate ores with carbon. In the future, a growing proportion of phosphorus output will probably be produced from phosphoric acid because thermal reduction of phosphate ore is energy-intensive.

- Phosphate additives for animal feed are produced primarily by calcination and when necessary by defluorination of phosphate concentrates.

Processing of chemical fertilizers.—Most phosphate used for the production of chemical fertilizers is prepared by digestion of concentrate in mineral acids (wet acidulation). Sulfuric acid and phosphoric acid produced in the process are used for this purpose; nitric acid is used often. The purpose of this acidulation process is to convert the phosphate in the ore to a soluble form, to precipitate calcium as calcium sulfate, and to prevent calcium ions from interfering adversely with succeeding steps in the process. The following five chemical reactions are steps in the processing of chemical fertilizers:

(1) Production of phosphoric acid

$$7Ca_{10}(PO_4)_6F_2+70H_2SO_4+140H_2O \rightarrow 42H_3PO_4+14HF+70CaSO_4 \cdot 2H_2O$$

(2) Production of triple superphosphate (TSP)

$$3Ca_{10}(PO_4)_6F_2+42H_3PO_4+30H_2O \rightarrow 30Ca(H_2PO_4)_2 \cdot H_2O+6HF$$

(3) Production of normal superphosphate (SSP)

$$10Ca_{10}(PO_4)_6F_2+70H_2SO_4+170H_2O \rightarrow 30Ca(H_2PO_4)_2 \cdot H_2O+20HF+70CaSO_4 \cdot 2H_2O$$

(4) Production of monoammonium phosphate (MAP)

$$NH_3+H_3PO_4 \rightarrow (NH_4)H_2PO_4$$

(5) Production of diammonium phosphate (DAP)

$$2NH_3+H_3PO_4 \rightarrow (NH_4)_2HPO_4$$

The phosphoric acid produced by the wet acidulation process contains 27 to 29 percent P_2O_5; the solution is then evaporated until it contains 52 to 54 percent P_2O_5 or becomes superphosphoric acid with 68 to 72 percent P_2O_5.

Certain technical considerations may be important in the formulation of policy in relation to industrial processing and supply of phosphate products. First, only phosphate concentrates of certain specifications can be used for the wet acidulation process. The P_2O_5 content should be as high as possible; in any case, it must be more than 30 percent. In addition, the carbonate content should be about 4 percent and must not exceed 6 percent. The maximum tolerable concentration of $R_2O_3(Fe_2O_3+Al_2O_3)$ is 3 percent, that of MgO is about 1.0 percent, and that of chlorine is 0.2 weight percent. Elevated concentrations of organic matter are also undesirable (these can be lowered by calcination), as are trace elements such as cadmium, lead, mercury, arsenic, and chromium.

Second, the material balance, taken partly from the stoichiometry shown in equation (1) and partly from experience with large plants for the treatment of phosphate concentrates by the wet acidulation process, is as follows (with reference to the amount of P_2O_5 produced):

Starting materials. About 3.5 tons of phosphate concentrate and 1 ton of sulfur or about 3 tons of H_2SO_4.

Products. 1 ton of P_2O_5 in the form of H_3PO_4, 5 to 5.5 tons of hydrated calcium sulfate, a maximum of 89 kg of fluorine as HF or 113 kg H_2SiF_6, of which about 40 kg of H_2SiF_6 are recoverable.

Third, little use has been found for the hydrated calcium sulfate produced in the reaction. Due to its fine grain size and numerous impurities, it cannot compete with gypsum which is widely available. As most of it must be dumped, many fertilizer plants are faced with acute disposal problems.

Finally, a prerequisite for the production of phosphate fertilizer is not only the availability of phosphate concentrate of a suitable composition, but also the availability of sulfur or sulfuric acid at a reasonable cost. The amount of sulfur needed for the production of phosphoric acid equivalent to 1 ton of P_2O_5 is about 1 ton; somewhat less, about 0.74 tons of sulfur, is needed for the production of a ton of triple superphosphate.

The more important phosphate chemicals produced by the wet acidulation process are shown in table 4 with their average P_2O_5 and nitrogen contents as compared with a phosphate concentrate. This compilation shows that choosing appropriate chemical processes for the production of phosphate fertilizers (for example, SSP, DAP, or TSP) must take into account the need to minimize transportation costs.

The phosphate concentrate chosen as an example in table 4 (73 percent BPL) and the normal superphosphate contain 66.6 and 78 to 84 percent, respectively, of substances that contribute little or nothing to their value as sources of phosphate. The concentration of this "ballast" is reduced to 56 percent at most in the high-analysis fertilizer triple superphosphate, and to about 35 percent in monoammonium phosphate or diammonium phosphate. The conversion to these higher grade products is characteristic of the development of the processing of phosphate ores by wet acidulation in the last 20 to 25 years because fewer intermediate and waste products need to be transported away from the plants. Other factors besides proximity to higher grade ores, however, must be considered in selecting the site for a fertilizer plant.

Processing of elemental phosphorus.—Elemental phosphorus is produced by thermal reaction of phosphate concentrate with coke and silica:

$$2Ca_5(PO_4)_3F + 8SiO_2 + 15\,C \rightarrow 3P_2 + 15CO + 6CaSiO_3 + Ca_4Si_2O_7F_2$$

Starting materials. 8 tons of phosphate concentrate (68 percent BPL), 2.8 tons of silica sand, 1.25 tons of coke, and 50 kg of petroleum coke and pitch.

Products. 1 ton of phosphorus, 7.7 tons of slag, 0.15 tons of ferrophosphorus containing 20 percent phosphorus, and 2,500 cubic meters of carbon monoxide at standard temperature and pressure. About 13,000 kWh of electrical energy are required per ton of phosphorus produced.

PHOSPHATE RESOURCES

On the basis of P_2O_5 content, more than 89 percent of identified global phosphate resources are in marine sedimentary deposits. Of the remainder, at least 10 percent are in igneous deposits, and less than 0.5 percent are in island phosphate deposits. Even given the necessary data about geology, size,

TABLE 4.—*Phosphate and nitrogen content of phosphate concentrates and several downstream products*

Product	Content	Remarks
Phosphate ore concentrate (73 percent BPL)	33.4 percent P_2O_5	---
Normal superphosphate (SSP)	16-22 percent P_2O_5	50:50 mixture of Ca-superphosphate and gypsum.
Triple-superphosphate (TSP)	44-48 percent P_2O_5	---
Phosphoric acid (merchant grade) (PA)	52-55 percent P_2O_5	The phosphoric acid from the acidulation process contains 27-29 percent P_2O_5, which is then concentrated.
Super-phosphoric acid	68-72 percent P_2O_5	---
Monoammonium phosphate (MAP)	52-55 percent P_2O_5 11 percent N_2	$NH_4H_2PO_4$
Diammonium phosphate (DAP)	46 percent P_2O_5 18 percent N_2	$(NH_4)_2HPO_4$

and grade, so many economic and political criteria have to be taken into account that it is very difficult to determine whether a phosphate deposit will be workable. In a time of general economic difficulty and especially a scarcity of foreign currency reserves, some countries will mine low-grade resources for their own use. On the other hand, for a bulk commodity such as phosphate, costs will be directly related to location. Assignment of resources to the thoroughly investigated, but not economic, categories (R1M and R1S) and to the insufficiently explored, but probably economic, category (R2E) is particularly difficult and often may be based on subjective estimation.

Economically exploitable resources in known deposits (r1E).—Economically recoverable phosphate resources are shown according to country, continent, and economic grouping, as well as for the world, in table 5.[5] Estimates of western World resources are based almost exclusively on data gathered for the individual deposits for the ISMI inventory. Recoverable world resources in the r1E category add up to about 8.8 billion metric tons of P_2O_5, but may be between 8.3 and 8.7 billion metric tons if incomplete data on recovery rates are taken into account.

Resources are concentrated in only a few countries. Morocco and Western Sahara alone have more than half the world's phosphate resources, the U.S.A. about a fifth, and the Soviet Union nearly a 12th; between them, they possess almost 80 percent of the r1E resources (table 5). Concentration of world economic resources is, therefore, even greater than that of production. The western industrial countries, the developing countries, and the central economy countries have 22, 67, and 11 percent, respectively, of the r1E resources. The distribution of the r1E resources among countries of different economic classes is shown in table 6 and figure 4.

Using the estimate of r1E resources, which contain 8.3 to 8.7 billion metric tons of P_2O_5, and 1981 world mine production, which contains about 45.6 million metric tons of P_2O_5, and assuming an average annual growth in production of 5 percent, these resources are sufficient to last for nearly 50 years.

Additional identified phosphate resources in known deposits and extensions thereto (R1M, R1S, and R2E).—Minable but insufficiently explored (R2E) and thoroughly explored but currently uneconomic (R1M and R1S) resources probably form extensions to every phosphate deposit now being mined, and they occur in many deposits from which phosphate is not currently being produced. The data on these resources could be improved considerably for many individual ore districts. Major efforts beyond the broader scope of this report, however, cannot be justified, especially for the vast identified subeconomic resources, which can include offshore deposits.

Addition of the numbers in the list of deposits in table 12 of Part II yields global estimates of more than 11 billion metric tons of P_2O_5 contained in R1M resources and more than 17 billion metric tons of P_2O_5 contained in R2E resources. The R1M resources in the Western World are estimated to be in Morocco (about 40 percent), the United States (about 27 percent), South Africa (about 21 percent), Egypt (about 5 percent), Australia (2.6 percent, when the resources in the Georgina basin where a mine was recently abandoned are assigned to the R1M category), Western Sahara (about 2 percent), and Tunisia (about 0.1 percent). The R2E resources in the Western World occur mainly in Morocco (about 75 percent), Peru (about 13 percent), the United States (about 4.5 percent), Tunisia (about 3 percent), and Egypt (about 2 percent).

PHOSPHATE PRODUCTION AND EXPORTS

World mine production of phosphate concentrate increased from 11.2 million metric tons in 1945 to 41.8 million metric tons in 1960, to nearly 85 million metric tons in 1970, and to 142.1 million metric tons in 1981. Cumulative production from 1945 to 1981 was about 2.37 billion metric tons of concentrate. Since 1945, the annual increase in production has averaged 6.8 percent, but the rate of increase declined and averaged only 5.0 percent a year in the decade from 1971 to 1981.

World mine production of phosphate concentrate is accounted for as follows: 80 percent from marine sedimentary deposits, 17 to 18 percent from igneous deposits, and 2 to 3 percent from island phosphate deposits. On the basis of P_2O_5 content, the proportions produced from igneous and island phosphate deposits would be greater than that indicated by percentage of concentrate.

[5]Industry analysts commonly refer to tons of phosphate concentrate (also called phosphate rock). In this report, some data are presented in terms of concentrate. Other data, such as those in table 5, are presented in terms of contained P_2O_5 in order to allow comparison between resources or production of different grades.

TABLE 5.—*World r1E phosphate resources by country, continent, and economic grouping*

[Figures are million metric tons of ore and of P_2O_5; *=industrial market countries]

	Ore tonnage	Estimated tonnage of P_2O_5 (r1E)	Percent of world P_2O_5 resources	Percent of Western World or central economy P_2O_5 resources
Western World				
Europe:				
*Finland	465	23.3	0.3	0.3
Asia:				
Turkey	23	3.9	0.04	0.1
Israel	282	77.6	.9	1.0
Jordan	1,167	362.9	4.1	4.7
Syria	28	7.9	.1	.1
Iraq	58	12.2	.1	.2
India	60	14.4	.2	.2
Sri Lanka	25	8.3	.1	.1
Total	1,643	487.2	5.6	6.3
Africa:				
Egypt	263	71.0	0.8	0.9
Algeria	311	80.2	.9	1.0
Angola	20	3.9	.04	.1
Morocco	13,190	4,220.8	48.1	54.3
W. Sahara	912	295.5	3.4	3.8
Senegal	175	52.0	.6	.7
Togo	91	27.3	.3	.4
Tunisia	315	89.8	1.0	1.2
*South Africa	2,561	179.3	2.0	2.3
Zimbabwe	30	2.3	.03	.03
Total	17,868	5,022.1	57.3	64.6
North America:				
*U.S.A.	6,305	1,712.9	19.5	22.0
Mexico	1,360	69.4	.8	.9
Total	7,665	1,782.3	20.3	22.9
South America:				
Peru	560	170.8	1.9	2.2
Brazil	2,750	261.3	3.0	3.4
Other (incl. Colombia)	40	12.0	.1	.2
Total	3,350	444.1	5.1	5.7
Oceania:				
Christmas Island	28	10.4	0.1	0.1
Nauru	23	8.4	.1	.1
Total	51	18.8	.2	.2
Western industrial market countries:	9,331	1,915.5	21.9	24.6
Developing countries	21,711	5,862.3	66.9	75.4
Total	31,042	7,777.8	88.7	100.0
Central economy countries				
Soviet Union	4,500	765.0	8.7	77.3
Vietnam	100	25.0	.3	2.5
China	1,000	200.0	2.3	20.2
Total	5,600	990.0	11.3	100.0
World total	36,642	8,767.8	100.0	n.a

Igneous deposits have increased significantly in importance during the last 15 years. The trend in share of P_2O_5 content produced form different types of deposits for the decade from 1971 to 1981 is shown in table 7. Production has been concentrated in only a few countries. Three countries, the United States, the Soviet Union, and Morocco, accounted for more than 70 percent of world production in every year. This predominance has weakened somewhat during the last decade: the U.S. share, which was nearly 50 percent in 1950, has dropped to about 38 percent.

TABLE 6.—*Phosphate resources in the world's major deposits and districts, by economic class of country*

Economic class[1]	GNP per capita 1980, U.S. dollars	Percent of r1E resources[2]
Industrial market (I) ---	>4,500	20.0
Upper middle-income (UM) --------------	1,360–4,500	11.9
Lower middle-income (LM) --------------	420–1,359	56.2
Low-income (L) -------	<410	.6
Central economy countries (low-income) (CL) --------	<410	2.6
Central economy countries (lower middle-income) (CLM) -------------	420–1,359	---
Industrialized central economy countries (CI) ---------------	>4,500	8.7

[1]Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1983, p. 148–149).
[2]Percent of total r1E resources from table 5 (8,768 million metric tons of P_2O_5).

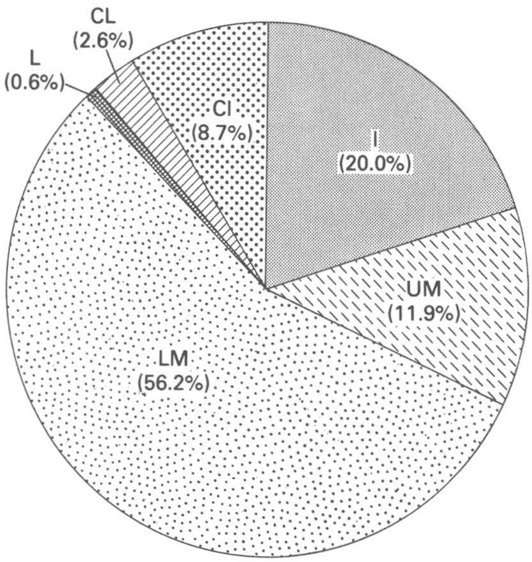


FIGURE 4.—Distribution of r1E phosphate resources in the world's major deposits and districts, by economic class of country. Economic class abbreviations are from table 6.

Production of concentrate in the three main producer countries, in the three country groups "western industrial market countries," "central economy countries," and "developing countries," and in the world is shown in figure 5 for the period from 1945 to 1981. The shares of production accounted for by the western industrial market countries and by the central economy countries stem primarily from the United States and the Soviet Union, respectively; Morocco accounts for 40 to 50 percent of the production of the developing countries.

TABLE 7.—*Proportions of total world production of phosphate by deposit type (based on P_2O_5 content), 1971–81*
[Average for first and last 5-year periods of the 11 years shown]

Deposit type	1971–75	1977–81
Marine sedimentary ----------------	78	76
Igneous -------------------------	17	21
Island phosphate ------------------	5	3

The three groups of countries have different production-growth rates. From 1950 through 1981, production from the central economy countries grew at an average annual rate of about 8.6 percent while the production from the western industrialized countries and the developing countries grew at an average annual rate of about 5.2 percent and 5.4 percent, respectively. As a result, the central economy countries increased their share of world production from about 13 percent in 1950 to 28 percent in 1981. The shares of the western industrial market countries and the developing countries decreased from about 49 percent and about 38 percent, respectively, in 1950 to about 42 percent and about 30 percent in 1981.

World production of phosphate concentrate was about 142 million metric tons in 1981. The average grade of these concentrates was 32.3±2.8 percent P_2O_5. The P_2O_5 content of the 1981 world production was, therefore, about 45.6 millon metric tons.

Annual world production of phosphate concentrates for the years 1979–81 is presented by country and country grouping in table 8 according to gross weight, and in table 9 according to estimated P_2O_5 content. The most important producing countries in 1981 with their percent of total concentrate production were: United States, 37.7; Soviet Union, 21.4; Morocco, 14.4; China, 5.9; Tunisia, 3.2; Jordan, 3.0; South Africa, 1.9; Brazil, 1.9; Israel, 1.7; and Togo, 1.6. The share of the three leading producer countries was over 73 percent; the top 10 countries accounted for more than 92 percent of world production. Table 8 also shows that the western industrial market countries accounted for 39.9 percent of world concentrate production in 1981, while the developing countries and central economy countries accounted for 32.1 and 28.0 percent, respectively.

Some of the major producing countries, especially those that are large in area, use most or all of

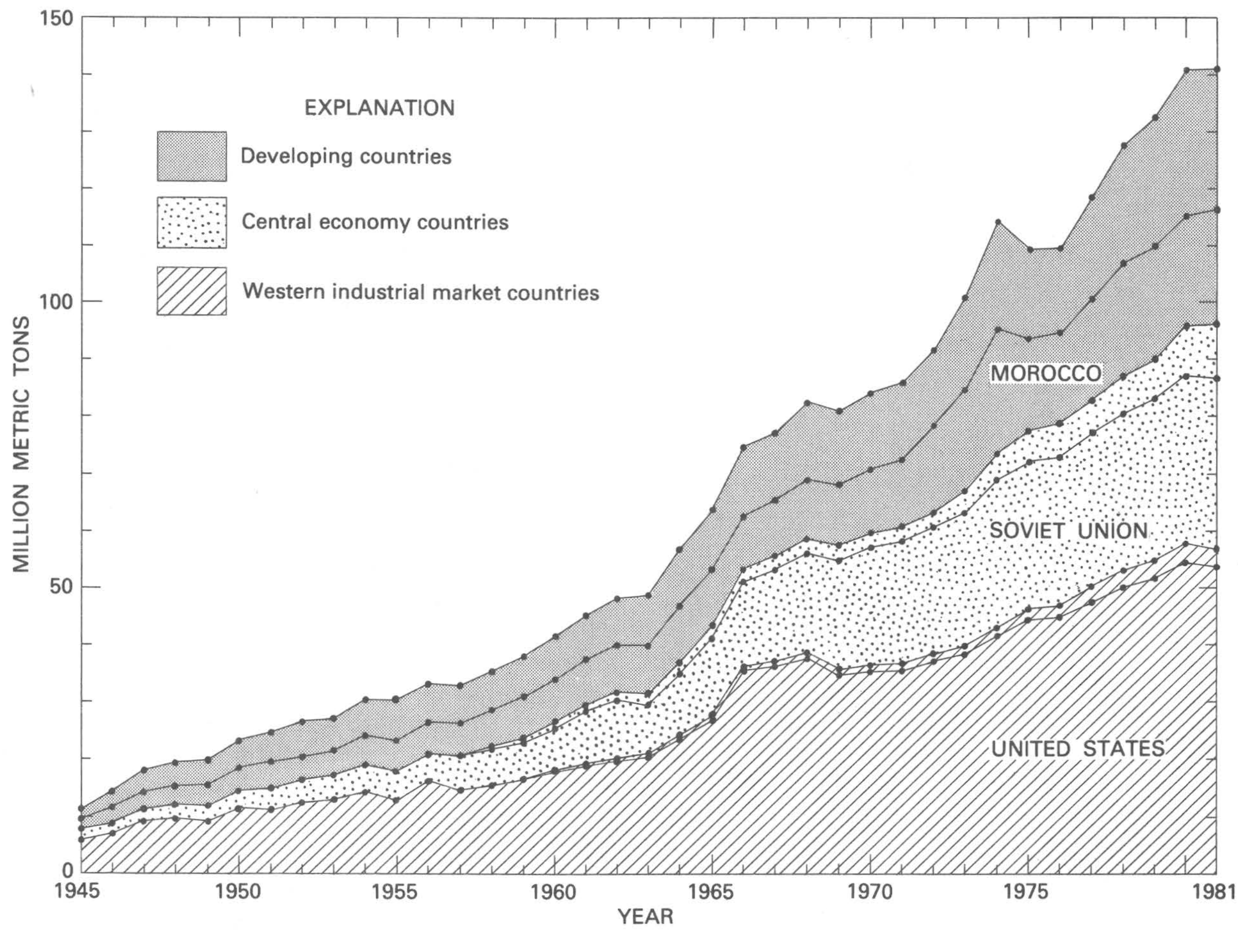


FIGURE 5.—World mine production of phosphate concentrate, 1945–81.

their own concentrate production for domestic purposes. In 1981, phosphate concentrate entering into trade amounted to 45.7 million metric tons of concentrate containing 15.0 million metric tons of P_2O_5. The main exporting countries (with their share of total world exports of P_2O_5 contained in phosphate concentrate in percent) were Morocco (34.4), United States (21.8), Soviet Union (10.7), Jordan (7.7), Nauru and Christmas Island (6.7), Togo (5.3), Israel (3.7), Senegal (2.9), Tunisia (2.1), Syria (1.9), and Algeria (1.8). Data on exports of P_2O_5 contained in phosphate-bearing material in all forms from the main phosphate-producing countries are presented in table 10.

An assessment of the importance to a producer country of its phosphate production and export industry can give an insight into supply vulnerability. This importance can be assessed by comparing the phosphate production of the individual countries with the per capita gross national product, using data from Weltbank (1982), and determining the ratio of the value of the exported phosphate ore concentrates (and in some cases, the export of fertilizers produced from them) to the total value of the exports of the individual producing countries.

The distribution of production of phosphate concentrates among countries of varying economic status can be seen in table 11 and figure 6. Most phosphate production (about 40.0 percent) is from industrial market economy countries (mostly from the United States), and about 21.4 percent is from industrialized central economy countries (in this case, only the Soviet Union). About 8.3 percent of the production of phosphate concentrate takes place in low-income countries, about 20.9 percent is produced in lower middle-income countries such as Morocco, Senegal, and Tunisia, and about 9.4 percent of the production takes place in upper middle-income countries including Algeria, Brazil, Israel, Jordan, and South Africa.

TABLE 8.—*World mine production of phosphate concentrate by country, continent, and economic grouping, 1979–81*

[Figures are thousand metric tons of concentrate; figures may not add to totals shown due to rounding]

Country	1979 Tonnage	1979 Percent of Western World	1979 Percent of world total	1980 Tonnage	1980 Percent of Western World	1980 Percent of world total	1981 Tonnage	1981 Percent of Western World	1981 Percent of world total
Europe									
*France	11	(1)	(1)	25	(1)	(1)	29	(1)	(1)
*Finland	3	(1)	(1)	138	0.1	0.1	201	0.2	0.1
*Sweden	58	0.1	(1)	88	.1	.1	124	.1	.1
Turkey	25	(1)	(1)	83	.1	.1	103	.1	.1
Total	97	.1	.1	334	.3	.2	457	.4	.3
Asia									
Israel	2,216	2.3	1.7	2,611	2.5	1.8	2,372	2.3	1.7
Jordan	2,828	2.9	2.1	3,911	3.8	2.8	4,244	4.1	3.0
Syria	1,272	1.3	1.0	1,319	1.3	.9	1,350	1.3	1.0
India	666	.7	.5	541	.5	.4	562	.5	.4
Indonesia	5	(1)	(1)	11	(1)	(1)	7	(1)	(1)
Philippines	6	(1)	(1)	42	(1)	(1)	42	(1)	(1)
Thailand	5	(1)	(1)	6	(1)	(1)	3	(1)	(1)
Total	6,998	7.1	5.2	8,441	8.2	5.9	8,580	8.4	6.0
Africa									
Egypt	631	0.6	0.5	668	0.6	0.5	708	0.7	0.5
Algeria	1,084	1.1	.8	1,035	1.0	.7	916	.9	.6
Morocco	20,000	20.4	15.0	19,357	18.7	13.6	20,393	19.9	14.4
Senegal	1,835	1.9	1.4	1,632	1.6	1.2	2,017	2.0	1.4
Togo	2,920	3.0	2.2	2,933	2.8	2.1	2,244	2.2	1.6
Tunisia	4,154	4.2	3.1	4,502	4.3	3.2	4,543	4.4	3.2
Kenya	---	---	---	---	---	---	1	(1)	(1)
*South Africa	3,221	3.3	2.4	3,285	3.2	2.3	2,718	2.7	1.9
Zimbabwe	136	.1	.1	130	.1	.1	122	.1	.1
Seychelles	7	(1)	(1)	4	(1)	(1)	5	(1)	(1)
Total	33,988	34.6	25.4	33,546	32.4	23.6	33,667	32.9	23.7
North America									
Mexico	274	0.3	0.2	397	0.4	0.3	355	0.3	0.2
*United States	51,611	52.5	38.6	54,415	52.6	38.4	53,624	52.4	37.7
Total	51,885	52.8	38.9	54,812	52.9	38.6	53,979	52.8	38.0
South America									
Brazil	1,589	1.6	1.2	2,562	2.5	1.8	2,658	2.6	1.9
Colombia	7	(1)	(1)	8	(1)	(1)	9	(1)	(1)
Peru	5	(1)	(1)	14	(1)	(1)	12	(1)	(1)
Netherland Antilles	49	(1)	(1)	---	---	---	---	---	---
Total	1,650	1.7	1.2	2,584	2.5	1.8	2,679	2.6	1.9
Australasia									
*Australia	8	(1)	(1)	7	(1)	(1)	5	(1)	(1)
Christmas Island	1,367	1.4	1.0	1,713	1.7	1.2	1,423	1.4	1.0
Nauru	1,828	1.9	1.4	2,087	2.0	1.5	1,480	1.4	1.0
Kiribati (Gilbert Island)	420	.4	.3	---	---	---	---	---	---
Total	3,623	3.7	2.7	3,807	3.7	2.7	2,908	2.8	2.0

TABLE 8.—*World mine production of phosphate concentrate by country, continent, and economic grouping, 1979-81*—Continued

	1979			1980			1981		
Country	Tonnage	Percent of Western World	Percent of world total	Tonnage	Percent of Western World	Percent of world total	Tonnage	Percent of Western World	Percent of world total
Western World Total	98,241	100.0	73.6	103,524	100.0	73.0	102,270	100.0	72.0
	1979			**1980**			**1981**		
Country/ economic grouping	**Tonnage**	**Percent of central economy countries**	**Percent of world total**	**Tonnage**	**Percent of central economy countries**	**Percent of world total**	**Tonnage**	**Percent of central economy countries**	**Percent of world total**
				Central economy countries					
Soviet Union	28,405	80.4	21.3	29,700	77.4	20.9	30,450	76.5	21.4
Vietnam	400	1.1	.3	500	1.3	.4	550	1.4	.4
China	6,055	17.1	4.5	7,700	20.1	5.4	8,370	21.0	5.9
Cambodia	---	---	---	5	(1)	(1)	5	(1)	(1)
North Korea	450	1.3	.3	450	1.2	.3	450	1.1	.3
Total	35,310	100.0	26.4	38,355	100.0	27.0	39,825	100.0	28.0
World total	133,551		100.0	141,879		100.0	142,095		100.0
Western industrial market countries	54,912		41.1	57,958		40.9	56,701		39.9
Developing countries	43,329		32.4	45,566		32.1	45,569		32.1
Central economy countries	35,310		26.4	38,355		27.0	39,825		28.0

[1]Less than 0.05.
*Western industrial market countries indicated by asterisks; other Western World countries are classified as developing countries.

The export of phosphate concentrates, phosphoric acid, and other downstream products accounts for a significant proportion of the total exports of several phosphate-producing countries. The ratio of phosphate concentrates and downstream products to total exports in terms of value is over 90 percent for Christmas Island and Nauru; between 30 and 50 percent for Jordan, Morocco, and Togo; and from 10 to 30 percent for Senegal and Tunisia.

FUTURE TRENDS

Many different factors, most of which are probably unforeseeable, will affect the future world pattern of phosphate supply. Three possible trends are currently apparent.

While shortages of supply are unlikely to occur as a result of ore depletion, there is little doubt that ores will in general become more difficult and costly to process as a high portion of material included in resource categories is of fine-grained carbonate type or contains certain detrimental elements such as magnesium and chlorine. These problems may well be adequately met, however, by advances in processing technology.

Certain countries may feel it necessary to develop indigenous marginally economic resources of phosphate in the interest of self-sufficiency or in order to save foreign currency. This could lead to loss of markets for phosphate concentrates and

TABLE 9.—*World mine production of phosphate, estimated P_2O_5 content, by country, continent, and economic grouping, 1979–81*

[Figures are thousand metric tons of P_2O_5 content; figures may not add to totals shown due to rounding]

Country	1979			1980			1981		
	Tonnage	Percent of Western World	Percent of world total	Tonnage	Percent of Western World	Percent of world total	Tonnage	Percent of Western World	Percent of world total
Europe									
*France	1.1	(1)	(1)	2.5	(1)	(1)	2.9	(1)	(1)
*Finland	1.1	(1)	(1)	49.7	0.1	0.1	72.4	0.2	0.2
*Sweden	22.0	0.1	0.1	33.4	.1	.1	47.1	.1	.1
Turkey	7.0	(1)	(1)	23.2	.1	.1	28.8	.1	.1
Total	31.2	.1	.1	108.8	.3	.2	151.2	.5	.3
Asia									
Israel	709.1	2.2	1.7	835.5	2.5	1.8	759.0	2.3	1.7
Jordan	933.2	3.0	2.2	1,290.6	3.9	2.8	1,400.5	4.3	3.1
Syria	394.3	1.2	.9	408.9	1.2	.9	418.5	1.3	.9
India	219.8	.7	.5	178.5	.5	.4	185.5	.6	.4
Indonesia	1.8	(1)	(1)	3.9	(1)	(1)	2.4	(1)	(1)
Philippines	2.1	(1)	(1)	14.7	(1)	(1)	14.7	(1)	(1)
Thailand	1.6	(1)	(1)	2.0	(1)	(1)	1.0	(1)	(1)
Total	2,261.9	7.2	5.3	2,734.1	8.2	6.0	2,781.6	8.5	6.1
Africa									
Egypt	208.2	0.7	0.5	220.4	0.7	0.5	233.6	0.7	0.5
Algeria	368.6	1.2	.9	351.9	1.1	.8	311.4	.9	.7
Morocco	6,600.0	20.9	15.4	6,387.8	19.2	14.0	6,729.7	20.5	14.8
Senegal	660.6	2.1	1.5	587.5	1.8	1.3	726.1	2.2	1.6
Togo	1,051.2	3.3	2.5	1,055.9	3.2	2.3	807.8	2.5	1.8
Tunisia	1,246.2	3.9	2.9	1,350.6	4.1	3.0	1,362.9	4.1	3.0
Kenya	---	---	---	---	---	---	.3	(1)	(1)
*South Africa	1,127.4	3.6	2.6	1,149.7	3.5	2.5	951.3	2.9	2.1
Zimbabwe	47.6	.2	.1	45.5	.1	.1	42.7	.1	.1
Seychelles	2.3	(1)	(1)	1.3	(1)	(1)	1.6	(1)	(1)
Total	11,312.1	35.8	26.4	11,150.6	33.5	24.5	11,167.4	34.0	24.5
North America									
Mexico	87.7	0.3	0.2	127.0	0.4	0.3	113.6	0.3	0.2
*United States	15,999.4	50.6	37.3	16,868.6	50.6	37.0	16,623.4	50.6	36.5
Total	16,087.1	50.9	37.5	16,995.6	51.0	37.3	16,737.0	50.9	36.7
South America									
Brazil	556.1	1.8	1.3	896.7	2.7	2.0	930.3	2.8	2.0
Colombia	1.8	(1)	(1)	2.1	(1)	(1)	2.3	(1)	(1)
Peru	1.6	(1)	(1)	4.5	(1)	(1)	3.8	(1)	(1)
Netherland Antilles	15.7	(1)	(1)	---	---	---	---	---	---
Total	575.2	1.8	1.3	903.3	2.7	2.0	936.4	2.9	2.3
Australasia									
*Australia	2.5	(1)	(1)	2.2	(1)	(1)	1.6	(1)	(1)
Christmas Island	492.1	1.6	1.1	616.7	1.9	1.4	512.3	1.6	1.1
Nauru	694.6	2.2	1.6	793.1	2.4	1.7	562.4	1.7	1.2
Kiribati (Gilbert Island)	151.2	.5	.4	---	---	---	---	---	---
Total	1,340.4	4.2	3.1	1,412.0	4.2	3.1	1,076.3	3.3	2.4

TABLE 9.—*World mine production of phosphate, estimated P_2O_5 content, by country, continent, and economic grouping, 1979–81*—Continued

Country	1979 Tonnage	1979 Percent of Western World	1979 Percent of world total	1980 Tonnage	1980 Percent of Western World	1980 Percent of world total	1981 Tonnage	1981 Percent of Western World	1981 Percent of world total
Western World Total -	31,607.9	100.0	73.7	33,304.4	100.0	73.1	32,849.9	100.0	72.1
Country/ economic grouping	1979 Tonnage	1979 Percent of central economy countries	1979 Percent of world total	1980 Tonnage	1980 Percent of central economy countries	1980 Percent of world total	1981 Tonnage	1981 Percent of central economy countries	1981 Percent of world total
Central economy countries									
Soviet Union --	9,089.6	80.5	21.2	9,504.0	77.5	20.9	9,744.0	76.5	21.4
Vietnam -----	128.0	1.1	.3	160.0	1.3	.4	176.0	1.4	.4
China --------	1,937.6	17.2	4.5	2,464.0	20.1	5.4	2,678.4	21.0	5.9
Cambodia ----	---	---	---	1.5	([1])	([1])	1.5	([1])	([1])
North Korea --	135.0	1.2	.3	135.0	1.1	.3	135.0	1.1	.3
Total ---	11,290.2	100.0	26.3	12,264.5	100.0	26.9	12,734.9	100.0	27.9
World total ----	42,898.1		100.0	45,568.9		100.0	45,584.8		100.0
Western industrial market countries ---	17,153.5		40.0	18,106.1		39.7	17,698.7		38.8
Developing countries ---	14,454.4		33.7	15,198.3		33.4	15,151.2		33.2
Central economy countries ---	11,290.2		26.3	12,264.5		26.9	12,734.9		27.9

[1]Less than 0.05.
*Western industrial market countries indicated by asterisks; other Western World countries are classified as developing countries.

downstream products in some countries that are currently major importers.

A progressively larger proportion of phosphate passing into trade will be in the form of phosphoric acid and other downstream products originating in phosphate-mining countries. This trend may lead to a slow decline in the phosphate-processing industries of importing countries. It is believed, however, that the development of indigenous downstream industries by countries which produce phosphate ore, though reducing opportunities among importers for adding value, will assist in stabilizing long-term supply.

SUMMARY

Phosphorus, the principal component of phosphate fertilizers, is essential to plant development and, therefore, decisive to the propagation of life on Earth. The world's major resources are located in only a few countries, and accordingly, phosphate is considered a strategic mineral commodity, especially by countries dependent on imported supplies.

Those world phosphate resources studied in enough detail to warrant economic exploitability amount to about 37 billion metric tons of ore (or

TABLE 10.—*Estimated exports of contained P_2O_5 (in phosphate concentrate, phosphoric acid, and fertilizer compounds) from phosphate-mining countries in 1981*

[Figures are thousand metric tons of P_2O_5 content]

Country	Phosphate concentrate	Phosphoric acid[1]	Fertilizer compounds[1]	Total
United States	3,270	762	3,974	8,006
Morocco	5,160	548	78	5,786
Soviet Union	1,606	---	234	1,840
Jordan	1,148	---	---	1,148
Tunisia	314	286	344	944
Togo	797	---	---	797
Israel	557	26	---	583
Nauru	519	---	---	519
Christmas Island	491	---	---	491
Senegal	434	---	---	434
South Africa	38	228	30	296
Syria	291	---	---	291
Algeria	269	---	---	269
Egypt	51	---	13	64
Sweden	35	---	17	52
Finland	---	---	36	36
Total	14,980	1,850	4,726	21,556

[1]Source: United Nations Food and Agriculture Organization, 1983.

about 29 billion metric tons of phosphate concentrate containing 8.8 billion metric tons of P_2O_5). A major portion is located in Morocco, which has almost 50 percent of the world total, followed by the United States, the Soviet Union, Jordan, Brazil, China, South Africa, and Tunisia.

Furthermore, additional identified resources of more than 155 billion metric tons of ore (equivalent to about 29 billion metric tons P_2O_5) that is either presumably exploitable but not yet studied in detail or is marginally economic can be assumed. Most of these resources are in Morocco, the United States, South Africa, and Peru. In some areas of especially high use of phosphate in agriculture (for example, western Europe) and highly populated countries (for example, India and Indonesia), only a few deposits are known.

World mine production of phosphate concentrate in 1981 totalled about 142.1 million metric tons (45.6 million metric tons of P_2O_5). The main producing countries, in terms of P_2O_5 content, were the United States (36.5 percent), the Soviet Union (21.4 percent), and Morocco (14.8 percent). Exports in all forms from mining countries in 1981 amounted to about 21.6 million metric tons of P_2O_5, of which about 70 percent was in phosphate concentrate; the balance was in phosphoric acid and fertilizer compounds. Principal exporting countries were the United States (37 percent; predominately downstream products), Morocco (27 percent; mainly concentrate), the Soviet Union (9 percent; mainly concentrate), and Jordan (5 percent, concentrate).

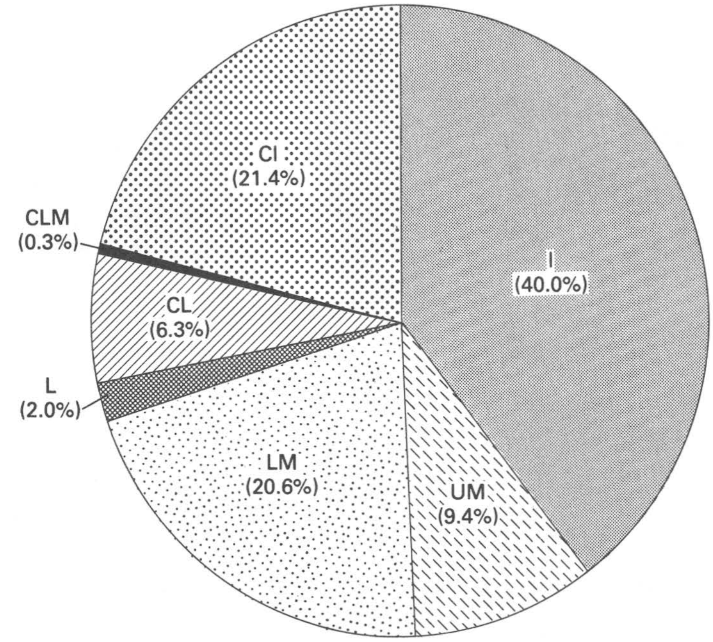
Shortages in world supply resulting from exhaustion of phosphate resources are unlikely to occur in the foreseeable future. But some trends that will in part affect the world supply pattern are apprent. First, phosphate ores to be mined in the future will become more difficult and costly to process with present-day technologies. Second, certain countries may aim to reach self-sufficiency by exploiting indigenous marginally economic resources. Finally, an increasing proportion of phosphate passing into trade will be in the form of phosphoric acid and other downstream products originating in phosphate-mining countries.

TABLE 11.—*World production and exports of phosphate in 1981, by economic class of country*

Economic class[1]	GNP per capita 1980, U.S. dollars	Percent of world production[2]	Percent of world exports[3]		
			Concentrates	Phosphoric acid and fertilizer compounds	All forms
Industrial market (I)	>4,500	40.0	28.8	72.8	42.2
Upper middle-income (UM)	1,360–4,500	9.4	13.4	4.3	10.7
Lower middle-income (LM)	420–1,359	20.6	41.7	19.3	34.9
Low-income (L)	<410	2.0	5.3	---	3.7
Central economy countries (low-income) (CL)	<410	6.3	---	---	---
Central economy countries (lower middle-income) (CLM)	420–1,359	.3	---	---	---
Industrialized central economy countries (CI)	>4,500	21.4	10.7	3.6	8.5

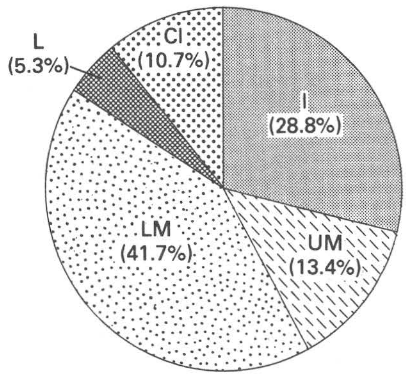
[1]Based principally on GNP per capita and, in some instances, other distinguishing economic characteristics (World Bank, 1983, p. 148–149).
[2]Percent of 1981 world concentrate production from table 8 (142.1 million metric tons containing 45.6 million metric tons of P_2O_5).
[3]Percent of P_2O_5 content of 1981 exports from table 10 (21.56 million metric tons).

PRODUCTION



EXPORTS

Phosphate Concentrates
(14.98 million tons)



Phosphoric Acid and Fertilizer Compounds
(6.58 million tons)

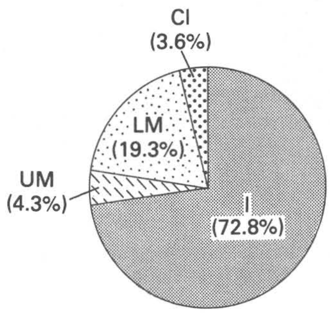


FIGURE 6.—Distribution of world production and exports of phosphate in 1981, by economic class of country. Economic class abbreviations are from table 11.

PART II—SELECTED INVENTORY INFORMATION FOR PHOSPHATE DEPOSITS AND DISTRICTS

Table 12 contains information from the International Strategic Minerals Inventory record forms for phosphate deposits and districts. Only selected items of information about the geology, mineral production, and resources of the deposits are listed here; some of this information has been abbreviated because of space limitations.

Summary descriptions and data are presented in the table as closely as possible to the way that they were reported in the inventory records. Data that were reported in units other than metric tons have been converted to metric tons for comparability. Some of the data in the tables are more aggregated than in the inventory records, such as cumulative production totals that for some mines have been reported by year or by groups of years. Some of the abbreviations used in the inventory records forms have been used in these tables; they are explained in the footnotes.

TABLE 12

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*

[Only the resource figures for the underlined deposits may be used for calculating resources of a country. The other resource figures are already incorporated in the former. Numbers in parentheses (1 through 73) correspond to deposits shown in figure 2; a dash in the parentheses indicates that the deposit is not shown in figure 2]
[Metric tons indicated by t]

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			CANADA			
Cargill/Ontario (1)	Magmatic, carbonatite/ alkalic; residual enrichment	1975	None	None	None	56.7×10^6 t ore, 20% P_2O_5, 1976 (R1M)
Martison Lake/ Ontario (-)	Magmatic, carbonatite/ alkalic	1982	None	None	None	140×10^6 t ore, 20% P_2O_5, 0.35% Nb_2O_5, 1982 (R2S; smaller tonnage of R1E possible)
Nemegos (Multi-Minerals)/Ontario (-)	Magmatic, carbonatite/ alkalic	1959	None	None	None	4.5×10^6 t ore, 21.9% apatite, 0.173% Nb_2O_5, 69.6% magnetite, 1959 (R1M)
			UNITED STATES			
Montana phosphate district (2)	Marine chemical sediment	1921	68,000 t, 24% P_2O_5, 1929; 1.3×10^6 t, 24% P_2O_5, 1964	8.7×10^6 t ore, 24% P_2O_5, 1929-62; 20×10^6 t ore, 24% P_2O_5, 1963-84	Surface and underground	608×10^6 t ore, 24% P_2O_5, 1983 (R1E)
Warm Springs Creek (2)	Marine chemical sediment	1912	Capacity about 160,000 t	---	---	---
SE Idaho phosphate district (3)	Marine chemical sediment, residual enrichment	1906	Production data combined with Montana and Utah; see Utah		Surface	1.038×10^9 t ore, 24.5% P_2O_5, 1983 (R1E); 4.197×10^9 t ore, 24.5% P_2O_5, 1983 (R1S); 9.8×10^9 t ore, 27% P_2O_5, 1983 (R2S)
Conda	Marine chemical sediment, residual enrichment	---	Production data combined with Montana and Utah; see Utah		Surface	65.3×10^6 t ore, 26.5% P_2O_5, 1975 (R1E); 10.4×10^6 t ore, 16.6% P_2O_5, 1975 (R1M); 73.7×10^6 t ore, 26.5% P_2O_5, 1975 (r2E)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
Gay	Marine chemical sediment, residual enrichment	---	1.63×10^6 t phosphate conc	---	Surface	---
Henry	Marine chemical sediment, residual enrichment	---	680,000 t, 1979	---	Surface	29×10^6 t ore, 28.4% P_2O_5, 1975 (R1E)
Maybe Canyon	Marine chemical sediment, residual enrichment	---	Output about 2.5×10^6 t	---	Surface	23.5×10^6 t ore, 28% P_2O_5, 1975 (R1E); 9.9×10^6 t ore, 18% P_2O_5, 1975 (R1S); 40.6×10^6 t ore, 25% P_2O_5, 1975 (R2E)
Wooley Valley	Marine chemical sediment, residual enrichment	1955	Capacity 0.8×10^6 t	---	Surface	16×10^6 t, 27% P_2O_5, 1975 (R1E); 1×10^6 t, 17% P_2O_5, 1975 (R1M); 11×10^6 t, 27% P_2O_5, 1975 (R2E)
Uinta Mountains, Crawford Mountains, Wasatch Range/Utah (4)	Marine chemical sediment	1889	---	---	Surface	854×10^6 t, 25% P_2O_5 and 640×10^6 t, 20% P_2O_5, 1983 (R1E)
Vernal	Marine chemical sediment	1915	Capacity 272,000 t phosphate conc	---	Surface	640×10^6 t, 20% P_2O_5 (R1E)
Brown-rock phosphate district/ Tennessee (5)	Marine chemical sediment, residual enrichment	1894	2.5×10^6 t phosphate conc, 26% P_2O_5, 1975; 1.4×10^6 t phosphate conc, 25% P_2O_5, 1981	100×10^6 t phosphate conc., about 25% P_2O_5, 1896-1982	Surface	15×10^6 t, 20-22% P_2O_5 (R1E)
Hooker Chemical	Marine chemical sediment, residual enrichment	1893	680,000 t, 19-23% P_2O_5, 1978	---	Surface	---

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			UNITED STATES—continued			
Brown-rock phosphate district/ Tennessee (5) (continued)						
Monsanto	Marine chemical sediment, residual enrichment	1935	1.99 x 10^6 t, 1979	---	Surface	---
Mount Pleasant	Marine chemical sediment, residual enrichment	1893	Plant capacity 550,000 t	---	Surface	---
North Carolina phosphate district (6)	Marine chemical sediment	---	3 x 10^6 t phosphate conc, 30% P_2O_5, 1982	30 to 40 x 10^6 t phosphate conc, 1965-82	Surface	1 x 10^9 t phosphate conc, 30% P_2O_5, 1983 (r1E); 8 x 10^9 t phosphate conc, 30% P_2O_5, 1983 (r1M)
Lee Creek	Marine chemical sediment	1951	4.2 x 10^6 t, 1979	---	Surface	2 x 10^6 t ore (R1E)
North Carolina Phosphate Corp.	Marine chemical sediment	1951	Expected capacity 3.4 x 10^6 t	---	Surface	300 x 10^6 t (R1E)
East Florida phosphate district (7)	Marine chemical sediment	1970's	None	None	---	1 x 10^9 t phosphate conc, 30% P_2O_5, 1982 (r1E)
South Florida phosphate district (7)	Marine chemical sediment	1950's	None	None	---	1 x 10^9 t phosphate conc, 30% P_2O_5, 1982 (r2E)
Land Pebble phosphate district/ Florida (7)	Marine chemical sediment	1888	40 to 45 x 10^6 t phosphate conc, 32% P_2O_5, 1975-80; 31 x 10^6 t, phosphate conc, 32% P_2O_5, 1982	> 900 x 10^6 t phosphate conc, 32-35% P_2O_5, 1890-1982	Surface	800 x 10^6 t phosphate conc, 32% P_2O_5, 1982 (r1E); 30 x 10^6 t phosphate conc, 30% P_2O_5, 1982 (r1M)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
Big Four	Marine chemical sediment	1910	Capacity 1.1×10^6 t phosphate conc, 1983	---	Surface	20×10^6 t phosphate conc, 1980 (r1E)
Bonny Lake	Marine chemical sediment	---	Capacity 2.9×10^6 t phosphate conc, 1983	---	Surface	Resources are almost exhausted (1983)
Clear Springs	Marine chemical sediment	---	Capacity 2.7×10^6 t phosphate conc, 1983	---	Surface	31×10^6 t phosphate conc (r1E)
Fort Green	Marine chemical sediment	1920	Capacity 2.6×10^6 t phosphate conc, 1983	---	Surface	100×10^6 t phosphate conc, average 31% P_2O_5 (r1E)
Fort Meade (Gardinier)	Marine chemical sediment	---	Capacity 1.8×10^6 t phosphate conc, 1983	---	Surface	---
Fort Meade (Mobil)	Marine chemical sediment	---	Capacity 3.2×10^6 t phosphate conc, 1983	---	Surface	---
Haynsworth	Marine chemical sediment	---	Capacity 3.0×10^6 t phosphate conc, 1983	---	Surface	---
Hookers Prairie	Marine chemical sediment	---	Capacity 2.5×10^6 t phosphate conc, 1983	---	Surface	131×10^6 t conc (r1E)
Kingsford	Marine chemical sediment	1920	Capacity 4.0×10^6 t phosphate conc, 1983	---	Surface	50×10^6 t conc (r1E)
Lonesome	Marine chemical sediment	---	Capacity 2.5×10^6 t phosphate conc, 1983	---	Surface	45×10^6 t conc (r1E)

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
UNITED STATES—continued						
Land Pebble phosphate district (continued)						
Nichols	Marine chemical sediment	---	Capacity 1.3×10^6 t phosphate conc., 1983	---	Surface	---
Noralyn	Marine chemical sediment	---	Capacity 4.9×10^6 t phosphate conc, 1983 (For Noralyn + Phosphoria mines)	---	Surface	Mine is expected to be mined out in 1983
Payne Creek	Marine chemical sediment	---	Capacity 2.7×10^6 t phosphate conc, 1983	---	Surface	100×10^6 t phosphate conc, average 31% P_2O_5 (r1E) (Resources of Payne Creek + Saddle Creek + Fort Green mines)
Phosphoria	Marine chemical sediment	---	See Noralyn mine	---	Surface	32×10^6 t phosphate conc, about 32% P_2O_5 (r1E)
Polk County mine	Marine chemical sediment	1974	---	---	Surface	---
Rockland	Marine chemical sediment	1920	Capacity 1.8×10^6 t phosphate conc, 1983	---	Surface	140×10^6 t phosphate conc, about 25% P_2O_5 (r1E)
Saddle Creek	Marine chemical sediment	---	Capacity 0.9×10^6 t phosphate conc, 1983	---	Surface	100×10^6 t phosphate conc, average 31% P_2O_5 (r1E)
Silver City	Marine chemical sediment	1906	Capacity 1.6×10^6 t phosphate conc, 1983	---	Surface	---
Stuart Tract	Marine chemical sediment	1975	---	---	Surface	88×10^6 t ore (R1E)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
Watson	Marine chemical sediment	---	Capacity 0.9 x 10^6 t phosphate conc, 1983	---	Surface	---
Duette	Marine chemical	1900	None, designed capacity 2.7 x 10^6 t phosphate conc	None	---	---
Four Corners development	Marine chemical sediment	1920	None, designed capacity 3.4 x 10^6 t phosphate conc	None	---	---
North Florida-South Georgia district (8)	Marine chemical sediment; reworked, concentrated	1930's	---	35 x 10^6 t phosphate conc, 1964-82	Surface	300 to 400 x 10^6 t phosphate conc, about 32% P_2O_5, Suwannee River + Swift Creek mines + Deep Creek prospect, 1983 (r1E); 300 x 10^6 t phosphate conc, 30-32% P_2O_5, North Lake City + Brooker-Dukes deposits, 1983 (r2E); 200 x 106 t phosphate conc, 30-32% P_2O_5 Osceola National Forest deposit, 1983 (r2E); 900 x 10^6 t phosphate conc, about 28% P_2O_5, scattered occurrences, 1983 (r2E+r2S)
Suwannee River, Florida	Marine chemical sediment	1960	Capacity 2.5 x 10^6 t phosphate conc, 1983	---	Surface	See North Florida-South Georgia district
Swift Creek, Florida	Marine chemical sediment	1960	Capacity 1.8 x 10^6 t phosphate conc, 1983	---	Surface	See North Florida-South Georgia district
			MEXICO			
San Juan de la Costa (9)	Marine chemical sediment	1976	0.73 x 10^6 t phosphate conc, 1980	---	Surface and underground	45.4 x 10^6 t ore, 18-20% P_2O_5, 1980 (R1E)

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			MEXICO—continued			
Santo Domingo (10)	Marine chemical sediment, placer	1950	Initial capacity (1982) will be 1.5×10^6 t phosphate conc with 32% P_2O_5	---	Surface	1.315×10^9 t ore, average 4.6% P_2O_5, 1980 (R1E); 16×10^9 t ore, 4.6% P_2O_5, 1983 (R2E)
			PERU			
Sechura (11)	Marine chemical sediment	1951	Production was expected to start 1981	---	Surface	560×10^6 t, 30.5% P_2O_5, 1980 (R1E)
			BRAZIL			
Anitápolis (19)	Magmatic carbonatite/ alkalic, residual enrichment	1927	Planned capacity (1983) 0.6×10^6 t phosphate conc with 36% P_2O_5	---	Surface	60×10^6 t ore, 8.5% P_2O_5, 1980 (R1E); 260×10^6 t ore, 6% P_2O_5, 1980 (R1E)
Jacupiranga (18)	Magmatic, carbonatite/ alkalic, residual enrichment	1940	396,000 t phosphate conc, 36% P_2O_5, 1980	1.5×10^6 t ore, 1943-64, 0.5×10^6 t phosphate conc, 1943-64	Surface	100×10^6 t ore, 5% P_2O_5, 1980 (R1E)
Araxá-Phosphate (16)	Magmatic, carbonatite/ alkalic, residual enrichment	1930's	Average 600,000 t phosphate conc, 35% P_2O_5, 1979-80	---	Surface	273×10^6 t ore, 13.1% P_2O_5, 1979 (R1E)
Paulista (13)	Marine chemical sediment	1951	7,959 t ore, 1980; 3,070 t phosphate conc, 1980	---	Surface	30.56×10^6 t ore, about 21% P_2O_5, 1980 (R1E); 11.18×10^6 t ore, 1980 (R2S)
Trauira (12)	Sedimentary, island phosphate	---	None	None	---	17.9×10^6 t ore, 7.3% P_2O_5, 1980 (R1M)
Patos de Minas (15)	Marine chemical sediment	1974	None, planned production 192,000 t conc, 24% P_2O_5	None	---	329.3×10^6 t ore, 12.6% P_2O_5, 1979 (R1E); 106×10^6 t ore, 8% P_2O_5, 1979 (R2E)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
Catalao I (14)	Magmatic, carbonatite/ alkalic, residual enrichment	1968	Capacities: FOSFAGO, 500,000 t phosphate conc, 38% P_2O_5, 1980; GOIASFERTIL, 620,000 t phosphate conc, 38% P_2O_5, 1982	---	Surface	FOSFAGO: 80 x 10^6 t ore, average 12% P_2O_5, 1979 (R1E); GOIASFERTIL: 147 x 10^6 t ore, average 8.9% P_2O_5, 1979 (R1E)
Tapira (17)	Magmatic, carbonatite/ alkalic, residual enrichment	---	12 x 10^6 t ore, 8.6% P_2O_5, 1980; 0.9 x 10^6 t phosphate conc, 36% P_2O_5, 1980	---	Surface	603.6 x 10^6 t ore, average 8.6% P_2O_5, 1978 (R1E); 145.4 x 10^6 t ore, average 8.6% P_2O_5, 1978 (R2E)
SOUTH AFRICA						
Langebaan (20)	Sedimentary, placer	1897	28,761 t phosphate conc, 29.5% P_2O_5, 1981	12.798 x 10^6 t phosphate conc 1943-82	Surface	60.7 x 10^6 t ore, average 8.6% P_2O_5, 1976 (R1E); 73.0 x 10^6 t ore, average 5.8% P_2O_5, 1976 (R1M)
Glenover (21)	Magmatic, carbonatite/ alkalic	1953	28,751 t phosphate conc, average 30% P_2O_5, 1980; 20,009 t phosphate conc, average 30% P_2O_5, 1982	0.926 x 10^6 t phosphate conc, 30% P_2O_5, 1961-82	Surface	250,000 t ore, average 28% P_2O_5, 1982 (R1E); 18 x 10^9 t ore, average 4.5% P_2O_5, 1982 (R1M)
Phalaborwa (22)	Magmatic, carbonatite/ alkalic	1906	2.996 x 10^6 t phosphate conc, 37% P_2O_5, 1980; 2.726 x 10^6 t phosphate conc, 37% P_2O_5, 1982	17.274 x 10^6 t phosphate conc, 37% P_2O_5, 1953-82	Surface	2.21 x 10^9 t ore, average 7% P_2O_5 (R1E); 18.37 x 10^9 t ore, average 7% P_2O_5 (R2E)
Schiel/Venda (22a)	Magmatic, carbonatite/ alkalic	1953	None	None	Not defined	109 x 10^6 t phosphate conc, 1964 (r1S)
ZIMBABWE						
Dorowa (23)	Magmatic, carbonatite/ alkalic	1938	Average 0.12 x 10^6 t phosphate conc, 36.6% P_2O_5	1.672 x 10^6 t phosphate conc, 1966-80	Surface	30 x 10^6 t ore, about 7.7% P_2O_5, 1980 (R1E)

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			ANGOLA			
Kondonakaski (24)	Marine chemical sediment, residual enrichment	1951	None, due to start production in 1982	None	Surface	20.3 x 10^6 t ore, average 18.5% P_2O_5, 1980 (R1E)
			TOGO			
Hahotoé-Kpogamé (25)	Marine chemical sediment, residual enrichment	1952	Average about 4.5 x 10^6 t ore, 30% P_2O_5, 1974-78	37.5 x 10^6 t ore, 30% P_2O_5, 1970-78; 26.28 x 10^6 t phosphate conc, 36.2% P_2O_5, 1963-78	Surface	91 x 10^6 t ore, 29.7% P_2O_5, 1981 (R1E)
			SENEGAL			
Taiba (26)	Marine chemical sediment, residual enrichment	1948	Average about 1.4 x 10^6 t phosphate conc, about 37% P_2O_5, 1975-80	About 35.4 x 10^6 t phosphate conc, about 37% P_2O_5, 1961-78	Surface	25 x 10^6 t ore, 30.9% P_2O_5, 1980 (R1E); 50 x 10^6 t ore, 1980 (R2E)
Thiès (27)	Marine chemical sediment, residual enrichment	---	Average about 97,000 t phosphate conc, 1976-80	About 3.4 x 10^6 t ore, 1970-81	Surface	50 x 10^6 t ore, 30% P_2O_5, 1976 (R1E); 100 x 10^6 t ore, 28-29.5% P_2O_5, 1980 (R1E)
			MOROCCO			
Bu-Craa/Western Sahara (28)	Marine chemical sediment	1947	Capacity about 10 x 10^6 t phosphate conc	6.246 x 10^6 t phosphate conc, about 36.6% P_2O_5, 1970-77	Surface	416 x 10^6 t ore, about 33% P_2O_5, 1980 (R1E); 496 x 10^6 t ore, 31-32.9% P_2O_5, 1980 (R1E); 688 x 10^6 t ore, about 31% P_2O_5, 1980 (R1M)
Ganntour (29)	Marine chemical sediment, residual enrichment	1970's	7.61 x 10^6 t phosphate conc, 1981	13.7 x 10^6 t phosphate conc, 1980-81	Surface and underground	3.49 x 10^9 t ore, 29.7% P_2O_5, 1982 (r1E); 4.18 x 10^9 t ore, 29.7% P_2O_5, 1982 (r1M); 16 x 10^9 t ore, 1982 (R2E)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
Youssoufia	Marine chemical sediment, residual enrichment	1873	About 5.5 x 10^6 t ore, 1980	About 95 x 10^6 t ore, 1931-81	Surface and underground	10 x 10^9 cu m ore, 1980 (R2E)
Ben-Guerir	Marine chemical sediment	---	1.588 x 10^6 t ore, 27.5-27.9% P_2O_5, 1981; planned production 3 x 10^6 t ore, 1982	2.186 x 10^6 t ore, 27.5-27.9% P_2O_5, 1980-81	Surface	35 x 10^6 t ore, 27.9% P_2O_5, 1982 (R1E); 1.3 x 10^9 t ore, 1982 (R2)
Oulad-Abdoun (30)	Marine chemical sediment, residual enrichment	1920's	About 18 x 10^6 t ore, 1982	About 290 x 10^6 t ore, 1921-81	Surface and underground	9.7 x 10^9 t, 31.6% P_2O_5, 1980 (R1E); 4.7 x 10^9 t, 24.7% P_2O_5, 1982 (R1M); 24 x 10^9 t, 31.6% P_2O_5, 1982 (R2E); 22 x 10^9 t, 24.7% P_2O_5, 1982 (R2S)
Sidi-Daoui	Marine chemical sediment, residual enrichment	1920's	About 9 x 10^6 t phosphate conc, 32.9-34.3% P_2O_5, 1980's	---	Surface	160 x 10^6 t, phosphate conc, 32.9-34.3% P_2O_5, 1982 (r1E); 130 x 10^6 t ore, 24.7% P_2O_5, 1982 (R1M)
Meaa-El-Arech	Marine chemical sediment	1920's	3 x 10^6 t ore, 1982	---	Surface	---
Meskala (31)	Marine chemical sediment	1920's	None	None	---	5 x 10^9 t ore, 32% P_2O_5, 1980 (R2E)
ALGERIA						
Djebel Onk (32)	Marine chemical sediment	---	Average 675,400 t phosphate conc, 28.8-29.7% P_2O_5, 1974-78	3.84 x 10^6 t phosphate conc, 1966-78	Surface	500 x 10^6 t ore, 24.3-27.5% P_2O_5, 1980 (R1E)
Le Kouif	Marine chemical sediment	1873	About 30,000 t ore, 1980	---	Underground	27 x 10^6 t ore, 29.8% P_2O_5, 1979 (R1M)
Mzaita (33)	Marine chemical sediment	---	---	---	Underground	11 x 10^6 t ore, 27% P_2O_5, 1979 (R1E); 17 x 10^6 t ore, 27% P_2O_5, 1979 (R1M)

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			TUNISIA			
Kalaa Khasba (35)	Marine chemical sediment	---	Capacity of 240,000 t saleable product	---	Underground	6×10^6 t, 27.2% P_2O_5 1970 (r1E)
Kef es Schfair (35)	Marine chemical sediment	---	About 536,000 t ore, 1976	---	Surface and underground	90×10^6 t, 1981 (r1E)
Mdilla (35)	Marine chemical sediment	1893	815,000 t phosphate conc, 1971; planned capacity 1.2×10^6 t phosphate conc, with 29.7-30.2% P_2O_5	---	Surface and underground	80×10^6 t ore, 1979 (R1E)
Metlauoi (35)	Marine chemical sediment	1895	About 700,000 t ore, 1977	---	Underground	9.5×10^6 t ore, 26% P_2O_5 (R1E); 4.2×10^6 t ore, 26% P_2O_5 (R1M); 40.9×10^6 t ore, 26% P_2O_5 (R2E)
Moulares (35)	Marine chemical sediment	1895	---	---	Surface and underground	25×10^6 t ore (R1E)
Mrata (35)	Marine chemical sediment	1890's	Capacity 1.2×10^6 t ore	---	Underground	23×10^6 t ore, 1981 (R1E); 24.8×10^6 t ore, 1981 (R1M)
Redeyef (35)	Marine chemical sediment	1899	Capacity 1.3×10^6 t ore	---	Underground	27×10^6 t ore, 26% P_2O_5, 1982 (R1E); 35.3×10^6 t ore, 26% P_2O_5, 1982 (R1M); 137.7×10^6 t ore, 1981 (R2S)
Sehib (35)	Marine chemical sediment	---	Planned capacity 1.8×10^6 t ore and about 1.3×10^6 t phosphate conc	---	Underground	40×10^6 t ore, 29% P_2O_5, 1981 (R1E); 14.43×10^6 t ore, 1974 (R2E)
Stra Ouertane (34)	Marine chemical sediment	---	None, planned capacity 4.6×10^6 t ore or phosphate conc (?) by 1987	None	---	3×10^9 t, 12-15% P_2O_5, 1981 (R2E+R2S)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			EGYPT			
Red Sea phosphate district (36)	Marine chemical sediment	---	258,000 t phosphate conc, 1980; 229,000 t phosphate conc, 1981	---	Underground	70 x 10^6 t ore, 9.2-12.8% P_2O_5, 1974 (R1E); 302 x 10^6 t ore, 1974 (R2E)
Safaga	Marine chemical sediment	1908	---	5.9 x 10^6 t ore, 1911-73	Underground	9 x 10^6 t ore, 1973 (R1E); 233 x 10^6 t ore, 1973 (R2E)
Qusseir	Marine chemical sediment	About 1900	---	14.8 x 10^6 t ore, 1912-73	Underground	48 x 10^6 t ore, 28.2-31.2% P_2O_5, 1974 (R1E); 53 x 10^6 t ore, 1974 (R2E)
El-Hamrawein	Marine chemical sediment	1964	None, planned capacity 1.2 x 10^6 t ore	None	Underground	10.65 x 10^6 t ore, 27.2% P_2O_5, 1965 (R1E); 400 x 10^6 t ore, 1977 (R2S)
Idfu-Qena district (37)	Marine chemical sediment, residual enrichment	About 1900	Capacity about 450,000 t ore	6.7 x 10^6 t ore, 1908-73	Surface and underground	216 x 10^6 t ore, 1974 (R1E); 1.483 x 10^6 t ore, average 21.6% P_2O_5, 1974 (R2S)
Abu Tartur (38)	Marine chemical sediment	1898	None	None	None	30 x 10^6 t ore, 28.7% P_2O_5, 1977 (R1E); 525 x 10^6 t ore, about 25.2% P_2O_5, 1980 (R1M)
			ISRAEL			
Arad (40)	Marine chemical sediment	---	---	---	Surface	40 x 10^6 t ore, average 28.4% P_2O_5, 1980 (R1E)
Beersheva (39)	Marine chemical sediment	1980	None	None	---	200 x 10^6 t ore, 31.1-33.9% P_2O_5, 1982 (R1E)

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
ISRAEL—continued						
Makhtesh (40)	Marine chemical sediment	---	562,000 t ore, 1978; 350,000 t ore, 1980	---	Surface	3×10^6 t ore, 30-32% P_2O_5, 1980 (R1E)
Nahal Zin (40)	Marine chemical sediment	1930	0.91×10^6 t ore, 1979; 1.2×10^6 t ore, 1980	2.397×10^6 t ore, 1978-80	Surface	130×10^6 t ore, 1980 (R1E)
Oron (40)	Marine chemical sediment	1950	Capacity 1.2×10^6 t ore	---	Surface	55×10^6 t ore, 22-28% P_2O_5, 1981 (R1E); 85×10^6 t ore, 20-26% P_2O_5, 1980 (R1M)
JORDAN						
Ruseifa (42)	Marine chemical sediment, residual enrichment	1903	Capacity 0.8×10^6 t phosphate conc, 1980	---	Surface and underground	71.4×10^6 t ore, 28.3-33% P_2O_5, 1980 (R1E); 147×10^6 t, 1982 (R1M)
Shediyah (41)	Marine chemical sediment, residual enrichment	1976	None	None	---	838×10^6 t ore, about 26.5% P_2O_5, 1980 (R1E)
Al-Hasa-Qatrana (42)	Marine chemical sediment, residual enrichment	1908	Capacity about 5×10^6 t, 1981	---	Surface and underground	279.9×10^6 t ore, about 29.7% P_2O_5, 1980 (R1E); 342×10^6 t ore, 1980 (R2S)
SYRIA						
Eastern A and B (44)	Marine chemical sediment, residual enrichment	1958	Capacity 1×10^6 t phosphate conc	---	Surface	65×10^6 t ore, about 27.5% P_2O_5, 1974 (R1E); 348×10^6 t, low-grade ore, 1974 (R2S)
Khneifiss (43)	Marine chemical sediment	1958	230,000 t, average production, 1971-74	1.464×10^6 t, 1971-July 1975; 1.025×10^6 t phosphate conc, 1971-July 1975	Surface	3.686×10^6 t ore, 28.8-29.6% P_2O_5, 1975 (R1E); about 6×10^6 t ore, 1975 (R1M); about 8×10^6 t ore, 1975 (R2S)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			IRAQ			
Akashat (45)	Marine chemical sediment	1960	Rated capacity 3.4 x 10^6 t, phosphate conc	---	Surface	57.8 x 10^6 t, 21% P_2O_5, 1982 (R1E); 432 x 10^6 t, 17.5-22.5% P_2O_5, 1981 (R1M)
			TURKEY			
Mazidagi (46)	Marine chemical sediment, residual enrichment	1960	Capacity 250,000 t, 1978	---	Surface	258 x 10^6 t, average 10% P_2O_5, 1978 (R1M)
			FINLAND			
Siilinjärvi (47)	Chemical sediment	1950	125,000 t apatite conc, 1979	---	Surface	465 x 10^6 t, 10 vol.% apatite, 1980 (R1E)
			SOVIET UNION			
Kovdor (48)	Magmatic, carbonatite/ alkalic	---	Capacity 880,000 t conc, 35% P_2O_5, 1982	3.82 x 10^6 t phosphate conc, 35% P_2O_5, 1976-82	Surface	113 x 10^6 t, 6% P_2O_5 1975 (?)
Khibiny (49)	Magmatic, carbonatite/ alkalic	1926	46.4 x 10^6 t ore, 15-18% P_2O_5, 1981; 16.7 x 10^6 t phosphate conc, 39.4% P_2O_5, 1981	95.1 x 10^6 t phosphate conc, 39.4% P_2O_5, 1976-81	Surface and underground	2.7 x 10^9 t, 18% P_2O_5, 1970 (?)
Kingisepp (50)	Marine chemical sediment	---	840,000 t phosphate conc, 28.5% P_2O_5, 1976	---	Surface	320 x 10^6 t, 6.5% P_2O_5, 1979 (?)
Maardu (51)	Marine chemical sediment	---	Capacity 250,000 t phosphate conc	---	Surface	---
Viatka Kama Rudnichny (55)	Marine chemical sediment	1917	Capacity about 200,000 t ground rock	---	Surface	---
Vurnary (54)	Marine chemical sediment	1930	---	---	Surface	---

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			SOVIET UNION—continued			
Lepatinsk (53)	Marine chemical sediment	---	Benefication capacity (1970) 950,000 t	---	Surface	---
Voskresensk (52)	Marine chemical sediment	---	2 x 10^6 t ground phosphate, 1980	---	Surface	---
Dimitrovsk (52)	Marine chemical sediment	1959	---	---	Surface	5 x 10^6 t ore
Schchigry (52)	Marine chemical sediment	---	---	---	Surface	---
Chilisai (56)	Marine chemical sediment	---	5.9 x 10^6 t ore, 14.7% P_2O_5, 1980	--	Surface	269 x 10^6 t ore, average 14.7% P_2O_5, 1979
Aktyubinsk (57)	Marine chemical sediment	1929	---	---	Surface and underground	800 x 10^6 t ore, 6-14% P_2O_5, 1980
Kara Tau district (58)	Marine chemical sediment	1936	13 x 10^6 t ore, 23-29% P_2O_5, 1980	---	Surface and underground	1.7 x 10^9 t ore, 20-25% P_2O_5, 1975
Oshurkov (59)	Magmatic, carbonatite/ alkalic	1962	None, planned output of 19 x 10^6 t crude ore	None	---	870 x 10^6 t ore, 4-5% P_2O_5, 1979
Seligdar (60)	Magmatic, carbonatite/ alkalic	1974	None	None	---	1.6 x 10^9 t ore, average 6.5% P_2O_5, 1981
			MONGOLIA			
Hubsugul (61)	Marine chemical sediment	1960	None	None	---	400 x 10^6 t, 28% P_2O_5 1970
			INDIA			
Jhamar-Kotra (62)	Marine chemical sediment	1968	320,000 t, 1974	---	Surface	16.3 x 10^6 t average 30% P_2O_5, 1977 (R1E); 32.9 x 10^6 t average 14% P_2O_5, 1977 (R1M)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			SRI LANKA			
Eppawella (63)	Magmatic, carbonatite/ alkalic, residual enrichment	1971	Small-scale production only	None	Surface	25×10^6 t, 33% P_2O_5, 1981 (r1E); 40×10^6 t, 1981 (R1E+R2E?)
			CHINA			
Fanshan (64)	Magmatic, carbonatite/ alkalic	1977	None	None	---	---
Tung Hai (65)	Marine chemical sediment	---	---	---	---	---
Feng-T'ai (-)	Marine chemical sediment	---	80,000 t, 20% P_2O_5, 1974	---	---	---
Nantung (65)	Marine chemical sediment	---	---	---	---	---
Chunghsiang (66)	Marine chemical sediment	---	600,000 t	---	Underground	---
Chingshan (66)	Marine chemical sediment	---	600,000 t ore, 30% P_2O_5, 1980	---	Underground	---
Emei (68)	Marine chemical sediment	---	---	---	---	---
Chinho (68)	Marine chemical sediment	---	---	---	---	---
Chingping (68)	Marine chemical sediment	---	---	---	---	---
Kaiyang (-)	Marine chemical sediment	---	---	---	---	---

TABLE 12.—*Selected geologic, production, and mineral-resource information from ISMI records for phosphate deposits and districts*—Continued

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
CHINA—continued						
Kunming (69)	Marine chemical sediment	---	1 x 10^6 t ore, 1979	---	---	400 x 10^6 t, 30% P_2O_5, 1978
Chayuanpo (67)	Marine chemical sediment	---	---	---	---	---
Haikou (69)	Marine chemical sediment	---	Designed capacity, 3 x 10^6 t ore	---	---	60 x 10^6 t, 1980
Kunyang (69)	Marine chemical sediment	1934	2 x 10^6 t ore, 28% P_2O_5, 1980	---	Surface	---
Chanchiang (-)	Marine chemical sediment	---	---	---	---	---
VIETNAM						
Lao Cai (70)	Marine chemical sediment	---	1.6 x 10^6 t ore, 22% P_2O_5, 1977	---	Surface	---
CHRISTMAS ISLAND						
Christmas Island (71)	Sedimentary, island phosphate	1887	1.3 x 10^6 t phosphate conc, 1981	---	Surface	13.5 x 10^6 t A-grade ore, 1982 (R1E); 14.3 x 10^6 t B-grade ore, 1982 (R1E); 140 x 10^6 t C-grade ore, 1978 (R1S) 1/
AUSTRALIA						
Duchess (72)	Marine chemical sediment	1966	0.2 x 10^6 t ore, 30.9% P_2O_5, 1982/3 2/	1.3 x 10^6 t ore, 30.9% P_2O_5, 1975-82	Surface	1.068 x 10^9 t ore, 17.1% P_2O_5, 1975 (R1M); 304 x 10^6 t ore, 18.8% P_2O_5, 1975 (R2S); 1.267 x 10^9 t ore, 10.8% P_2O_5, 1975 (R2S)

Site name	Deposit type	Year of discovery	Annual production	Cumulative production	Mining method	Resources
			NAURU			
Nauru Island (73)	Sedimentary, island phosphate	About 1900	Average 1.5×10^6 t phosphate conc, 39.9% P_2O_5, 1980-81	About 50×10^6 t ore, 1900-74; about 20.76×10^6 t phosphate conc, 1900-81	Surface	23×10^6 t ore, about 36.6% P_2O_5, 1982 (R1E)

1/ Christmas Island phosphates are classified as A-grade, B-grade, and C-grade. The C-grade rock is an aluminum- and phosphate-rich subsoil derived by weathering and phosphatization of carbonate and volcanic rocks. The A-grade ore is principally fine-grained apatite overlying limestone and is the highest grade of ore on the island. The B-grade material is a mixture of A-grade and C-grade material and forms a transitional zone between them (Mew, 1980, p. 195-196).

2/ Production stopped since January 1983.

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