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THE PHOSPHATE ROCK INDUSTRY IN NORTH AND WEST AFRICA

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PREFACE

The study reported herein began as an investigation into the possible occurrence of phosphate rock in Ghana and its use as an aid to agricultural development there. It was expanded into a review of the phosphate rock industry in the whole of North and West Africa when the importance of the industry and the wider problems of the Sahel and surrounding regions became evident.

The country names have been updated to follow the changes of the early 1970's. Dahomey is now knows as Benin. Portuguese Guinea is now Guinea-Bissau. Spanish Sahara was renamed Western Sahara after Spain ceded the territory to Morocco in 1974. Subsequently Morocco and Mauritania each annexed portions so that Western Sahara no longer exists in any real sense.

Of a variety of literature consulted in preparing this report, several references were particularly useful. The most valuable single reference was The British Sulphur Corporation's *World Survey of Phosphate Deposits* (British Sulphur Corporation, 1971). United States Bureau of Mines Information Circulars 7814 and 7951 (Ruhlman, 1958; Waggaman and Ruhlman, 1960) were also valuable. Publications of various United Nations organizations provided excellent statistical summaries of phosphate rock mining, processing, exports, and imports. Among individual authors, Dr. G. Donald Emigh, Director of Mining for Monsanto Industrial Chemicals Company, stands out (Emigh, 1972, 1973a, 1973b, 1975, 1976). Dr. Emigh's papers plus Lewis, 1970; McKelvey, 1967; U.S. Bureau of Mines, 1976; United Nations, 1976; Food and Agriculture Organization, 1975; Notholt, 1968; and Couston, 1968 should be consulted by any investigator of phosphate.

Confirmation of tentative information in the available literature was provided by Norman Ulsaker, Development Resources, U. S. Agency for International Development. University of Arizona Professors John M. Guilbert, Department of Geosciences; William C. Peters, Department of Mining and Geological Engineering; and N. G. Wright, Office of Arid Lands Studies, reviewed the early manuscript and offered helpful suggestions and criticisms. Nancy Ferguson, research associate, Office of Arid Lands Studies, Robert K. McClure, graduate student in the Department of Geosciences, and Bonnie Stewart, graduate student in Oriental Studies assisted in compilation of data.

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INTRODUCTION

The phosphate rock industry has its own terminology. Some important terms are defined and discussed in the following section to help the reader understand better not only what follows in this report but also other phosphate rock literature.

Phosphate Rock. The phosphate rock of marine sedimentary deposits contains one or more phosphate minerals, usually of the apatite mineral family. The most important apatite mineral in marine sedimentary rocks is francolite, a carbonate fluorapatite ($Ca_5(PO_4,CO_3)_3F$). *Phosphorite* is defined as "a deposit of phosphate directly or indirectly, of sedimentary origin, which is of economic interest" (Emigh, 1975). *Phosphate rock* is the commercial term for any mined, mined and processed, fluorine-containing calcium phosphate used as a raw material for the next stage of manufacturing (Emigh, 1973a); also included are phosphatized limestones, sandstone shales, and igneous rocks (Lewis, 1970). Sedimentary phosphate rock is usually of fine grain sizes (<1mm) that facilitate its mining and processing.

Grade of Phosphate Rock. The phosphate rock industry does not have a standard method for expressing the calcium phosphate content of phosphate rock. Three terms are in use:

TPL - triphosphate of lime

P_2O_5 - phosphorous pentoxide

BPL - bone phosphate of lime

Triphosphate of lime is the compound, tricalcium orthophosphate - $Ca_3(PO_4)_2$. The P_2O_5 notation is another way of expressing the phosphate content of phosphate rock, fertilizers, or chemicals. The abbreviation, TPL, and symbol, P_2O_5, are most often read today. A simple relationship exists between TPL and P_2O_5; 1 unit of TPL = 0.458 units of P_2O_5, or 1 unit of P_2O_5 = 2.183 units of TPL. Bone phosphate of lime is the trade name for TPL or triphosphate of lime; BPL is now considered to be archaic.

Units of Weight. Phosphate rock and phosphate fertilizer production are reported in the following units of weight (Emigh, 1975):

tonne or mt	= metric ton (2205 lb.)
ton or lt (outside the United States)	= long ton (2240 lb.)
ton (in the United States)	= short ton (2000 lb.)
s. ton or st	= short ton (2000 lb.)

In this report all weights are given in metric units.

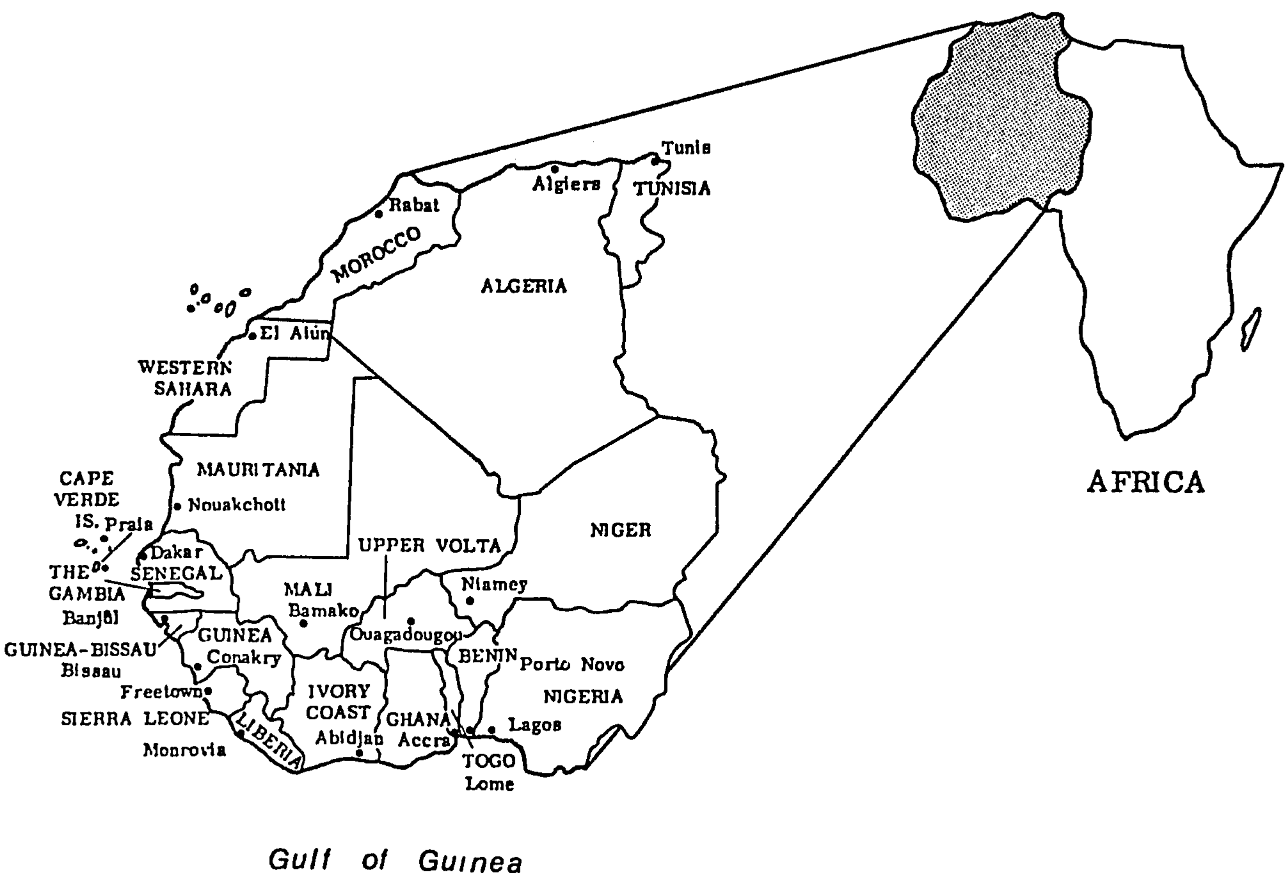

Figure 1

Map of Study Area

MINING AND EXPLORATION

The area of our concern includes 19 countries in North and West Africa which lie principally west of longitude 10° East. Their combined areas amount to about 8.7 million km^2 or almost 29 percent of the total area of the African continent. The countries are Algeria, Benin, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Mauritania, Morocco, Niger, Nigeria, Senegal, Sierra Leone, Togo, Tunisia, Upper Volta, and Western Sahara (Fig. 1).

Five countries (Algeria, Morocco, Senegal, Togo, and Tunisia) are currently mining and exporting phosphate rock. Algeria, Morocco, and Tunisia have long histories of phosphate rock mining and export (British Sulphur Corporation, 1971). The first deposits worked in Algeria and Tunisia were discovered in 1873, with actual production beginning in 1893 and 1899, respectively. Although some of the earliest mines are now exhausted, continued exploration has located additional deposits now in production or under development. Morocco began production in 1922 at the Khouribga deposits, followed in 1932 with production from the Youssoufia (formerly Louis Gentil) mining area. Today Morocco ranks third in world production and first in phosphate rock exports.

While phosphate rock occurs in Benin, Ghana, Mali, Niger, Nigeria, and Upper Volta, the occurrence there currently is economically unimportant because of low grade and/or small deposit size. Mauritania's deposits contain large amounts of low-grade material but have been considered only for small-scale extraction and use in local agriculture; the Guinea-Bissau deposit has been known since 1950 but no interest in its development has been shown (British Sulphur Corporation, 1971).

All phosphate rock mined in the study area is of marine sedimentary origin and consists of oolitic or pelletal phosphate, a pseudo-oolitic or gritty phosphate rock, and coprolitic phosphate rock. Phosphatic clays, marls, and limestones are associated with the mined phosphate rock, but are not considered ore. At the Pallo Mine in Senegal laterization has altered the phosphate rock to a calcium aluminum phosphate (British Sulphur Corporation, 1971).

The phosphate rocks vary in phosphate content. Deposits near Thies in Senegal contain beds with P_2O_5 content over 35 percent (British Sulphur Corporation, 1971) several Moroccan deposits exceed 30 percent P_2O_5, whereas deposits in Togo and Tunisia contain just under 30 percent P_2O_5. If economic conditions change in the future, the mining of lower grade phosphatic rocks may become economically feasible.

Mining Areas

Table 1 lists the mining areas for the six countries possessing known economic phosphate rock deposits. In Algeria and Morocco, the government controls the mines. In Tunisia, Senegal, and Togo, private industry shares control with the government.

The Bu-Crea deposits in Western Sahara were controlled by the Spanish government until Spain relinquished its claims to the territory in 1974. Morocco and Mauritania have not settled their dispute over a boundary for areas each claimed, but Morocco annexed two thirds or about 180,000 square km in the north, including the mines at Bu-Crea. The mines are currently idle although Morocco plans to put them back into production (Emigh, 1976; Gretton, 1976).

Exploration

Exploration for phosphate rock has been facilitated by two natural factors. First, all known deposits and reserves occur in marine sedimentary rocks of Late Cretaceous to Early Tertiary (Paleocene and Eocene) age. Cretaceous sediments were deposited in coastal strips (Benin to Ivory Coast), in coastal embayments or gulfs (Senegal region), and in the Sahara Sea that extended from Morocco to Egypt and southward around mountain masses into Nigeria to the Gulf of Guinea (Furon, 1959, 1963). Indeed, this marine transgression took place as the modern Atlantic Ocean was formed in the Createaceous. Marine transgressive sedimentation continued with but few interruptions into the Paleocene and Eocene in North Africa and southward into the Sahara-Mali region. Similar deposits were laid down on the west coast in Senegal, Ghana, Togo, Benin, and Nigeria (Furon, 1963). Second, the sedimentary rocks of Late Cretaceous and Early Tertiary age are exposed at the surface or occur near the surface beneath an overburden which is strippable in many areas.

Exploration thus is guided by previous experiences plus the general principle that new deposits may be associated with known fields. Straightforward geologic methods then come into play for which the exploration of deposits in Algeria and Tunisia is a good example. These deposits occur chiefly in the limbs of asymmetric anticlines exposed at the surface. Routine field mapping established the presence of similar structures so that when the earliest known deposits were worked out, operations successfully moved to a nearby area of like character (Stowasser, 1976a, 1976b, 1978).

The known Moroccan deposits lie in a northeast-southwest trending belt of Upper Cretaceous and Eocene sedimentary rocks (British Sulphur Corporation, 1971). Exploration has continued

TABLE 1

Phosphate Rock Mining in North and West Africa

Location	Description of Deposit	Ownership
Algeria		
1. Djebel Onk; in eastern Algeria, 20 km from the Tunisian border; linked by rail to the Mediterranean port of Annaba, 320 km to the north.	Mixed coprolitic and pseudo-oolitic phosphate rock; open-pit mining; in sedimentary rocks of Paleocene and Eocene age.	Government of Algeria
Tunisia		
All deposits are located in western Tunisia.		
1. Redeyef, Ain Moulares, and Metlaoui; west of Gafsa; railway connects mines with port of Sfax, 250 km to the East.	Pelletal phosphate beds; underground mining; in sedimentary rocks of Paleocene age.	Government of Tunisia
2. Djebel M'Dilla; 20 km south of Gafsa; linked by rail to Sfax.	Pelletal phosphate beds; underground mining; in same rocks as above.	Government of Tunisia
3. Kalaa-Djerda; near Kef, 400 km southwest of Tunis; connected by rail to port facilities outside Tunis.	Pelletal phosphate beds; underground mining; in same rocks as above.	Government of Tunisia; French Company
4. Kef Sehefera, M'rata, Sehib*	Open-pit, underground, underground mining, respectively.	
Morocco		
1. Khouribga; 120 km south of Casablanca to which it is linked by rail.	Oolitic sand or pelletal phosphate rock; open-pit and underground mining; in sedimentary rocks of Eocene age.	Government of Morocco
2. Youssoufia; 70 km east of the port of Safi with road and rail connections. The Ben Guerir mine is located 70 km east of Youssoufia. Mining is by open-pit methods.	Pelletal phosphate rock; underground mining; in sedimentary rocks of Eocene age.	Government of Morocco
Western Sahara		
1. Bu-Craa; 100 km SSE of El Aaiun; crushed phosphate rock transported to coast by a conveyor belt system almost 100 km in length.	Oolitic or pelletal phosphate rock; open-pit mining; in sedimentary rocks of Paleocene age.	Controlled by Morocco (1977)
Senegal		
1. Taiba; 40 km north of Thies; linked by rail (113 km) to port of Dakar.	Pelletal phosphate rock; surface mining; in sedimentary rocks of Middle Eocene age.	Private companies chiefly; Senegal government owns less than 4%.
2. Pallo Mine; north of Thies near Lam-Lam; linked by rail to Dakar.	Laterized phosphate beds of calcium aluminum phosphate; open-pit mining; in same rocks as above.	Private company.
Togo		
1. Hahotoe Mine; in southern Togo 25 km from the port of Kpeme.	Oolitic phosphate rock; open-pit mining; in clays and shales of Middle Eocene age.	Government of Togo; United States and French companies.

Source: British Sulphur Corporation, 1971.

*Mines at these locations are now open, but no details of deposit or ownership were available (Stowasser, 1973) in this belt with plans to develop mines at Benguerir and Sidi Hajjaj near Youssoufia, and in the Meskala region, located east of the seaport, Essaouira (Stowasser, 1976a).

Phosphate rock was first discovered in Western Sahara in 1948. Exploration by geologic mapping, drilling, pitting, and trenching began in 1962 to prove the phosphate rock body at Bu-Crea (anon., 1965).

The phosphate rock deposits of Senegal and Togo were discovered after World War II. Significant low-grade deposits are also known in Benin, Mali (north and northeast of Gao), Mauritania, and Nigeria (southwest); a sedimentary phosphate deposit also has been reported from Guinea-Bissau (British Sulphur Corporation, 1971).

Exploration for phosphate rock deposits is in progress in many of the countries. Few private mining companies are operating in the phosphate rock industry in Africa; the trend is toward nationalization of industries, and future exploration probably will be dominated by national governments or public enterprises.

MINING METHODS

Phosphate rock is mined underground in Tunisia, underground and by open-pit in Morocco, and by open-pit in the other producing countries (British Sulphur Corporation, 1971). Underground mining operations in Tunisia and Morocco are favored by the relative softness of the phosphate rock. Although termed "rock", the ore is rather friable and sandy, a property that also works against the mining operations since the "room and pillar" method of mining employed requires much timbering to keep overhead slabs from falling. The underground mining is highly mechanized.

Because open-pit mining methods using heavy equipment permit large volumes of overburden and phosphate rock to be moved at the least expense, underground methods, even in Morocco, are gradually giving way to open-pit operations. Photographs showing open-pit mining methods and equipment in use in Algeria, Tunisia, Morocco, and Senegal leave no doubt as to the large size of these operations (British Sulphur Corporation, 1971). Pictured and described are bulldozers, shovels, trucks, draglines, and bucket wheel excavators. In many instances the same equipment is used for stripping overburden and removal of phosphate rock. Combinations of equipment -- large capacity shovel and truck, dragline and truck, bucket wheel excavator and belt conveyor -- are chosen for the most efficient operation. The harder overburden and phosphate rock found in a few locations must be drilled and blasted before removal by other equipment. Cost increases are offset by the large quantities of phosphate rock moved annually.

Once mined, the phosphate rock is transported to the processing plant by rail, or if the plant is nearby, by long conveyor belts. The Bu-Crea deposits in Western Sahara have a special problem because a zone of shifting sand dunes blocks the construction of any permanent highways between the mine and the coast. Therefore ten spans of conveyor belts were constructed to transport rock a distance of nearly 100 km (British Sulphur Corporation, 1971).

TABLE 2

Upgrading and Processing Methods for Phosphate Rock

Location	Methods
1. Khouribga, Morocco	Rock is soft, friable to powdery with larger flint nodules. Ore is conveyed to vibrating screens; oolitic grains size range is from about 0.8 mm to less than 0.15 mm. Wet phosphate is dried to 1.5% moisture content; grade is 75% TPL. Some phosphate also is calcined at 950°C to remove organic matter and carbonates. The plant at Beni Idir uses a similar system and produces 75% and 70% TPL grades. The plant at Oued Zem processes 70-76% TPL podzolized rock by screening and then washing and stirring to make a slurry. After passing through a battery of hydrocyclones (centrifugal separators) for desliming, the material is centrifuged and dried to less than 20% moisture content. Final grade is 80-82% TPL.
2. Youssoufia, Morocco	Phosphate rock is screened and then dried to 1.4% moisture content; grade is 70-72% TPL
3. Bu-Craa, Western Sahara	The oolitic phosphate ore is silty and clayey with chert and carbonate rock impurities. After crushing and screening to remove the coarser impurities, the material is transported to El Aaiun on the coast where it is crushed further and washed in seawater. The coarser sizes go to waste. All undersize material passes through hydrocyclones with the fines going to waste. Fresh water is used to wash the concentrates which are then dried to less than 1% moisture content. Final grades are 75% and 80% TPL.
4. Taiba, Senegal	The ore is first scrubbed and screened to remove flinty material (non-ore); minus 20 mm particles are then ground to under 0.8 mm and passed through hydrocyclones to remove clay. Two particle size ranges, 0.3-0.8 mm and minus 0.3 mm, are treated separately to concentration by cell flotation. Iron and aluminum oxides and siliceous material are removed. The two sizes are recombined and dried to a concentrate of 80-83% TPL.
5. Pallo Mine, Senegal	The ore is calcium aluminum phosphate from a laterized phosphate bed. Ore is crushed and screened to three sizes: 4-10 mm, 10-40 mm, and 40-70 mm. Some ore is calcined to a phosphate fertilizer (34% P_2O_5) at the plant.
6. Hahotoe Mine Togo	Ore is scrubbed in seawater followed by wet screening. Clay, an abundant impurity, is removed by hydrocycloning. The concentrate is then washed to reduce salinity and dried to 1% moisture content. Additional screening of the dry material removes particles greater than 400 microns; at the same time electromagnets remove ferrous material.
7. Djebel Onk, Algeria	Ore requires considerable crushing and screening to give an 8 mm material. Desliming in vertical classifiers removes most of the clayey and siliceous impurities. Calcining at 850° - 950°C raises the grade from 62.5% to 69.5% TPL. Additional washing with carbonation removes lime and magnesia. The concentrate is further classified in vertical classifiers and dried to a 0.3% moisture content. Grade is 75.5% TPL.
8. Tunisia	Processing techniques vary from mine to mine. Crushed and screened rock is washed or subjected to air separation. Some rock is further washed with phosphoric acid to produce a grade of 70-73% TPL. Other processed ores from mined beds give grades ranging from 65 to 70% TPL. Some calcining is done at Kalaa-Djerda.

Source: British Sulphur Corporation, 1971.

PROCESSING

Phosphate rock processing usually begins at or near the mining site to prepare the rock for delivery to the buyer. Processing ranges from simple wet screening and drying of a rock grade that is already saleable, to the more complicated processes designed to raise the grade. Although selective mining of phosphate rock beds avoids waste rock, impurities of chert (silica), carbonate rock fragments, and clay minerals still may occur in the ore. Because of impurities, the ores from the Baiba mining center in Senegal and the Hahotoe mine in Togo require the most treatment. Upgrading and processing methods for each mining center are described in Table 2.

Single superphosphate is made by leaching sulphuric acid through phosphate rock. The final product, a mixture of calcium sulphate (gypsum) and calcium phosphate, sets hard and must be ground up. Triple superphosphate is made by a similar process using phosphoric acid as the leaching agent (Ahn, 1970).

Fertilizer plants producing superphosphates are located in Morocco at Safi, in Algeria at Annaba, in Senegal, in Tunisia at Sfax, Gabes, and Tunis, and in Nigeria at Kaduna (British Sulphur Corporation, 1971; Emigh, 1973b; and Fruglie, 1978). These plants supply the domestic market as well as the export market. Ivory Coast is manufacturing and exporting finished fertilizers. The U. S. Bureau of Mines reported that Togo was planning the construction of a fertilizer complex to supply domestic needs and provide a surplus for export. This review has not found the complex in operation as of early 1978. There also are preliminary plans for fertilizer production in Mali (Fruglie, 1978).

TABLE 3

Reserves, Production and Trade of Phosphate Rock and Products

Country	Reserves[1] 1,000,000 MT 1973	Production[2] 1000 MT 1975	Rock Exported[3] 1000 MT 1973	Raw Materials Imported[3] 1000 MT* 1973	Fertilizer Manufactured[2] 1000 MT** 1975/76	Fertilizer Exported[3] 1000 MT** 1973	Fertilizer Imported[3] 1000 MT** 1973
Algeria	100	802(1974)	218	105***	64.5	—	—
Ghana	—	—	—	0.3	— —	—	15
Ivory Coast	—	—	—	n(1972)	6.6	—	6.1(1972)
Liberia	—	—	—	n	—	—	1.2
Mali	—	—	—	2.9(1971)***	—	—	—
Mauritania	—	—	—	—	—	—	0.4(all forms)
Morocco	9100****	14,119 19,750(1974)	16,100	n(1972)	116.0 148.8(1974/75)	262	n
Nigeria	—	n(1973)	6	23.8	—	—	40.9
Senegal	120	1,600 1,878(1974)	1,416	n	20.0 23.8(1974/75)	77.7	0.66
Togo	—	1,100 2,553(1974)	1,793(1972)	0.7(1971)***	—	0.3	—
Tunisia	450	3,512 3,826(1974)	2,468	134	145.0 184.8(1974/75)	407	—
Western Sahara	1500	3,300 2,168(:974)	655	—	—	—	—

— = none or no data n = negligible amount

* includes rock and sulphur sources
** in terms of phosphoric acid (P_2O_5)
*** includes manufactured fertilizer
**** minimum, may be as much as 36,000

Sources: [1]Stowasser, 1976a,b
[2]UN Statistical Yearbook, 1976
[3]U.S. Bureau of Mines Minerals Yearbook, 1977

No data for Benin, Gambia, Guinea, Guinea-Bissau, Niger, Sierra Leone, and Upper Volta

PRODUCTION AND TRADE

Table 3 provides a summary of available data on reserves, mining, manufacturing, and international trade in phosphate rock and products in the study area. Unfortunately, the data are incomplete for many of the countries and somewhat inconsistent among the various sources.

Production at the Bu-Craa mines in Western Sahara was increasing rapidly before operations ceased in 1975. Three of the major phosphate rock producers -- Morocco, Senegal, and Tunisia -- are exporting phosphate rock and some finished fertilizer materials, principally to European markets. Algeria, Togo, and Western Sahara export large quantities of phosphate rock. Ivory Coast and Nigeria are the only other countries manufacturing any significant quantity of fertilizer materials. However, in both cases all feed stocks are imported with the phosphate rock coming from Togo (U. S. Bureau of Mines, 1977).

In Table 3, 'Raw Material Imported' refers to the raw materials or feed stocks employed in the manufacture of fertilizers. The chief feed stocks for phosphate fertilizers are phosphate rock and a sulfur source (sulfur, pyrite) to make sulfuric acid. Only Algeria, Ghana, Nigeria, and Tunisia import significant quantities of raw materials or phosphate fertilizers. Liberia imported basic slag phosphate (1972), a byproduct of the iron and steel industry in Europe which is ground to a finer size and then applied directly to the soil.

Producers in the study area hold 70 percent of the world's total known phosphate rock reserves, while the United States holds 14 percent. Only the United States (chiefly Florida) and U.S.S.R. exceed the production in Morocco, and these African countries could possibly dominate world production before the year 2000 and certainly take over as the leaders after the year 2000. The United States, U.S.S.R., and Morocco furnished 78 percent of the world supply of phosphate rock in 1973; if the production from the other five countries is included, the figure increases to 86 percent. The combined production from the six African countries now exceeds that of the U.S.S.R. (Stowasser, 1976a, 1976b).

USE OF PHOSPHATE AS FERTILIZER

The 19 countries of North and West Africa clearly are not at the same economic level, with per capita income ranging from Algeria ($570) and Tunisia ($410) to countries lying principally south of the Sahara with per capita income as low as $70 in Upper Volta (Balima, 1976). While Algeria, Morocco, and Tunisia possess a variety of natural resources and industries, agriculture was the largest contributor to the gross domestic product in eighteen of the nineteen countries; mining income exceeded agricultural income only in Liberia (UNIDO, 1970). The authors doubt that these statistics have changed significantly since 1970, even with Togo becoming a major producer of phosphate rock during the first half of the 1970's.

The Ivory Coast ($340/yr.; oil refinery, fertilizer manufacturing, mining, timber, and agricultural exports) and Ghana ($300/yr.; hydroelectric power, aluminum industry, mining, timber, oil refinery) are the economic leaders south of the Sahara, with Nigeria ($130/yr.; crude oil production, mining, agricultural exports) rapidly emerging (UNIDO, 1970; Balima, 1976).

Such differences have an obvious impact on the use of phosphate rock or fertilizer by the individual countries. Consumption of phosphate rock or fertilizers and problems of low demand are discussed in the following sections.

Fertilizer Consumption

Many soils of North and West Africa are deficient in phosphate, which results in lowered agricultural productivity. The addition of some form of phosphate, therefore, frequently results in increased productivity (Ahn, 1970).

Between the winter of 1961 and summer of 1965, almost 5000 simple fertilizer trials and 18,000 demonstrations were carried out by FAO in the West Africa countries of Benin, Gambia, Ghana, Nigeria, Senegal, and Togo (over 78 percent in Ghana and Nigeria). The trials and demonstrations showed an average yield increase to the most favorable fertilizer application of 71 percent (Couston, 1968). No indication was given as to the specific response to the addition of phosphate.

Ground phosphate rock, calcined rock and ground slag dissolve more slowly than rock treated with sulfuric or phosphoric acid to

TABLE 4

Annual Phosphate Fertilizer Consumption

Country	Consumption[1] Total (1000 MT) 1975/76	Per Hectare[2] (Kg)	Per Capita (Kg)
Algeria	76.6	5.81	4.9
Benin	1.4	—	0.5
Gambia	0.6	0.63	1.2
Ghana	8.9	0.35	1.0
Guinea	0.4	—	0.1
Guinea-Bissau	—	—	—
Ivory Coast	10.7	0.23	2.3
Liberia	0.5	—	0.3
Mali	0.4	0.22	0.1
Mauritania	0.1	—	0.1
Morocco	64.5	4.98	3.9
Niger	—	—	—
Nigeria	16.1	0.3	0.3
Senegal	15.6	0.89	3.8
Sierra Leone	2.0	0.27	0.8
Togo	1.2	—	0.6
Tunisia	25.6 (16.0 ground rock)	4.70	4.7
Upper Volta	0.4(1974/75)	—	—
Western Sahara	—	—	—

1 - in terms of P_2O_5

2 - arable land

— = none, negligible or no data

Source: FAO Annual Fertilizer Review, 1975 make a superphosphate fertilizer. Increased productivity may be observed immediately when using the manufactured superphosphates, but positive results from the application of ground phosphate rock take at least two growing seasons. However, the ground rock has a long-lasting effect and may increase yields for several years after application (Ahn, 1970).

Table 4 presents data on consumption of phosphate fertilizer in total and in relation to arable land and population. The consumption per hectare of arable land is an indicator of the intensity of fertilizer consumption.

Algeria, Morocco, and Tunisia have the highest consumption of phosphate fertilizer per hectare and per capita. South of the Sahara, Senegal leads in consumption per hectare and in consumption per capita. Guinea-Bissau, Niger and Western Sahara have no indication of phosphate fertilizer consumption, but doubtlessly use at least small amounts (UNIDO, 1970). Six countries -- Gambia, Guinea, Liberia, Mali, Mauritania, and Upper Volta -- show annual consumption figures of less than 1,000 metric tons. The general trend in phosphate fertilizer consumption is increasing in North and West Africa (FAO, 1976).

Problem of Low Demand

In most of the countries south of the Sahara, fertilizer demand is low or fertilizer has a low market potential. The reasons for the low demand and low potential are both general and specific.

Factors impeding the increase of fertilizer use can be summarized as follows (UNECA, 1968):

(a) The high cost of fertilizers and lack of foreign exchange; transport charges represent a large proportion of the total cost of fertilizers.

(b) Lack of adequate supplies of fertilizers and an inadequate distribution system.

(c) Lack of information on the kinds and amounts of fertilizer needed and on methods of application in specific circumstances.

(d) The relatively low standard of crop husbandry for most African crops.

(e) Very low basic yields of some crops, particularly food crops.

(f) The lack of adequate seed and of disease and insect control measures and other practices that are necessary if fertilizers are to have their best effect.

(g) The low value of many crops grown in the region, e.g. cassava, bananas, and maize. (High value crops may be adequately fertilized.)

(h) Additional labor required to apply fertilizer at a busy time of the year.

(i) Tenure systems which tend to discourage the use of fertilizers.

(j) Limitations of natural resources -- soils thin or eroded, climate too dry or too wet.

Algeria, Morocco, and Tunisia exceeded projections of phosphate fertilizer consumption to 1970 and 1975 handsomely, but south of the Sahara, only Benin and Mali managed to exceed the projections for 1970 (UNIDO, 1970).

CONCLUSIONS

Extensive phosphate rock deposits in Algeria, Morocco, Senegal, Togo, Tunisia and Western Sahara contain 70 percent of the known total world reserves of that mineral. Similar geologic conditions not yet fully explored suggest the possibility of further discoveries in countries of North and West Africa, specifically Benin, Ghana, Guinea-Bissau, Mali, Mauritania, and Nigeria.

Large-scale, highly mechanized mining operations are being conducted in Algeria, Morocco, Senegal, Togo, and Tunisia. The mines in Western Sahara are temporarily idle following political conflict between Mauritania and Morocco. (Morocco presently controls the mines there.) There may be opportunities for smaller scale, less mechanized mining supplying crushed rock for local use in some of the other countries with known deposits.

Production, in general, is increasing as is the export of phosphate rock. Crude ore is upgraded before shipping. Principal countries receiving exports are France, Spain, Belgium-Luxembourg, United Kingdom, and Poland. In addition, Togo exports phosphate rock to Ivory Coast and Nigeria.

Plants for the production of superphosphate fertilizers are operating in Algeria, Ivory Coast, Morocco, Nigeria, Senegal, and Tunisia. Some phosphate fertilizers are being exported, principally to European countries.

Annual consumption of phosphate rock and/or phosphate fertilizer in the individual countries is variable but relatively low although research has shown conclusively the need for and response to phosphate by soils in the area. Highest annual consumption of fertilizer is in Algeria (76,600 mt) which also has highest consumption per hectare of arable land (5.81 kg) and per capita (4.9 kg). Tunisia has highest consumption of ground phosphate rock (16,000 mt). Based on available statistics, several countries (Guinea-Bissau, Niger, and Western Sahara) use a negligible amount of either ground phosphate rock or phosphate fertilizer.

The phosphate rock industry is important to the countries of North and West Africa for at least two reasons. First, it makes a substantial and vital contribution to the economy in employment and capital formation, and second, it supplies a much needed input for increasing agricultural production. Unfortunately, because the resource is not uniformly distributed, the countries of the region do not share equally in its benefits. Ways to integrate regional development of the industry and the utilization of phosphate would seem to be worth exploring.

There is a need for a concerted effort by the governments of the countries of North and West Africa and by other interested governments acting individually and through bi-national and multi-national agreements and agencies to improve the phosphate rock industry and utilization of phosphate in the area. Constraints to such development can and must be lessened. The data base needs to be improved particularly as to location and extent of phosphate rock deposits and on ways to improve local, small-scale mining and use. It may be possible to substitute locally obtained crushed rock for expensive imported fertilizers. The consequent slower release of phosphate to the soil and eventually to the crops should not be a deterrent in a situation where, in many cases, no phosphate is being applied.

Finally, there is a continuing need to extend the information available on the technology of phosphate use to the farmers themselves, and to insure that adequate supplies of phosphate are available at reasonable cost.

REFERENCES CITED

Ahn, Peter M. (1970) West African soils. In West African Agriculture, 3d ed., v. 1. Oxford University Press, London. 332 p.

Anonymous (1965) Phosphate prospecting in the Spanish Sahara. In E. H. Beard, W. A. Campbell, and A. H. Simpson, eds., Overseas geology and mineral resources. Overseas Geological Surveys, Quarterly Bulletin 9(4):443-444.

Balima, S. A. (1976) Overview of economic and development problems of West Africa. In P. Paylore and R. A. Haney, Jr., eds., Proceedings of the West Africa Conference, April 11-15, 1976, Tucson, Arizona, p. 20-24. University of Arizona, Tucson.

British Sulphur Corporation (1971) World survey of phosphate deposits. 3d ed. British Sulphur Corporation, Ltd., London. 180 p.

Couston, J. W. (1968) The fertilizer programme of the Food and Agriculture Organization of the United Nations under the Freedom From Hunger Campaign, its purpose and accomplishment. In UNIDO, Fertilizer production, technology and use. Papers presented at the UN Interregional Seminar on the Production of Fertilizers, Kiev, Ukrainian SSR, 1965, p. 362-369. United Nations, New York.

Emigh, G. D. (1972) World phosphate reserves: Are there really enough? Engineering and Mining Journal 173 (4):90-95.

--- --- (1973a) Phosphate rock. Mining Engineering 25(1):42-45.

--- --- (1973b) Economic phosphate deposits. In E. J. Griffith, et al, eds., Environmental phosphorus handbook, p. 97-116. John Wiley & Sons, N. Y.

--- --- (1975) Phosphate rock. In S. J. Lefond, ed., Industrial minerals and rocks. 4th ed., p. 935-962. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., N. Y.

--- --- (1976) Phosphate rock. Mining Engineering 28 (3):43-44.

Food and Agriculture Organization of the United Nations (1976) Annual fertilizer review, 1975. FAO, Rome. 191 p.

Fruglie, W. (1978) Personal communication. U. S. Agency for International Development, Washington, D. C., Development Resources.

Furon, R. (1959) Le crétace du Sahara et de l'ouest Africain. In El sistema cretacico, un symposium sobre el cretacico en le hemisferio occidental y su correlación mundial, p. 83- 96. Congreso Geológico International, XX Sesión, Ciudad de México.

--- --- (1963) Geology of Africa. Oliver and Boyd, Edinburgh. 377 p.

Gretton, John (1976) A desert state that vanished. Geographical Magazine 49 (3):155-160.

Lewis, R. D. (1970) Phosphorus. In Mineral Facts and Problems. U. S. Bureau of Mines, Bulletin 650:1139-1155.

McKelvey, V. E. (1967) Phosphate deposits. U. S. Geological Survey, Bulletin 1252-D. 21 p.

Notholt, A. J. G. (1968) Phosphate exploration techniques. In Seminar on Sources of Mineral Raw Materials for the Far East, p. 214-228. United Nations, Mineral Resources Development Series 32.

Ruhlman, E. R. (1958) Phosphate rock. 1: Mining, beneficiation, and marketing. U. S. Bureau of Mines, Information Circular 7814. 33 p.

Stowasser, W. F. (1976a) Phosphate rock. In Minerals yearbook, 1974, 1: Metals, minerals, and fuels, p. 1063-1081. U. S. Bureau of Mines, Washington, D. C.

--- --- (1976b) Phosphate rock. In Mineral facts and problems, 1975. U. S. Bureau of Mines, Bulletin 667:819-834.

--- --- (1978) Personal communication. U. S. Bureau of Mines, Division of Nonmetallic Minerals.

United Nations (1977) Statistical yearbook, 1976. United Nations, New York, Department of Economic and Social Affairs.

United Nations Economic Commission for Africa (UNECA) (1968) Fertilizer production and consumption in Africa. In UNIDO, Fertilizer production, technology and use. Papers presented at the UN Interregional Seminar on the Production of Fertilizers, Kiev, Ukrainian SSR, 1965, p. 20-30. United Nations, New York.

United Nations Industrial Development Organization (UNIDO) (1970) Directory of fertilizer production facilities. I: Africa. United Nations, New York. 271 p.

U. S. Bureau of Mines (1977) Minerals yearbook, 1974. 3: Area reports, international. Washington, D. C. 1193 p.

Waggaman, W. H. and E. R. Ruhlman (1960) Phosphate rock. 2: Processing and utilization. U. S. Bureau of Mines, Information Circular 7951. 36 p.