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Fertilizer Production in Pakistan: Present Problems and Future Plans

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Tennessee Valley Authority

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Foreword

This report presents information collected by the authors during a ~~three~~ 3-week visit to Pakistan in June 1974 and recommendations resulting from this study. The authors were employed by the Tennessee Valley Authority (TVA) and were assigned to this work at the request of the U.S. Agency for International Development (USAID) to assist the Government of Pakistan (GOP) and its agency, the National Fertilizer Corporation (NFC), to identify problems limiting fertilizer production in Pakistan, suggest means for increasing production, and assist with long-range planning of additional fertilizer facilities, especially phosphate facilities. Special attention was paid to indigenous phosphate deposits in the Hazara District of the Northwest Frontier Province because of the profound effect this material could have on plans for phosphate fertilizer production.

At the request of USAID and NFC, the team's main efforts were directed toward short-term improvements in production capabilities of the present NFC plants. Suggestions for longer-term planning and for future production facilities are outlined to help define the scope of work for a recommended study by a subsequent team.

The authors wish to express their thanks for the cooperation of all of the people who helped provide information for this report. It was not possible to record the names of all who participated, but a partial list is appended to the report.

We were impressed by the enthusiasm and competence of most of the people we talked with, and with their progressive attitude. We believe these qualities foretell a bright future for Pakistan.

Summary of Recommendations

1. Improved procurement of sulfur is needed to insure maximum utilization of the superphosphate facilities at Jaranwala and Lyallapur. It is recommended that NFC appoint a procurement officer to be responsible for a continuous, adequate supply of sulfur and other materials by direct negotiations with suppliers and by scheduling and expediting shipments.

2. Granulation of superphosphate is recommended to improve its quality. The granular superphosphate should be conditioned to prevent deterioration of bags, and the free acid content should be controlled. Technical information on granulation has been supplied to NFC.

3. Excess ammonia that is available from Dawood-Hercules could be utilized by transporting it to Multan for processing into urea and ammonium nitrate-limestone (ANL). Also, consideration should be given to developing a market for ammonia or aqua ammonia for direct application to the soil or in irrigation water.

4. A specialist in ammonia production technology should be employed to recommend means for increasing the output of the Multan plant.

5. Development and utilization of the Hazara phosphate rock deposits should be accelerated. Steps that should be taken include:

a. Long-term leases or contracts should be negotiated to accelerate development of proven reserves.

b. Exploration of all promising deposits should be intensified.

c. Mining of the most accessible deposits should start immediately to supply at least part of Pakistan's present needs. Techniques for utilizing the Hazara rock for superphosphate should be developed.

d. The feasibility of beneficiating the lower grade phosphate ore should be determined.

e. Consultation or participation of mining experts or companies should be sought for long-term, large-scale operations. Individuals or companies with experience in the United States western phosphate fields should be well qualified.

6. A complete independent study should be made to formulate a recommended long-range program for expansion of fertilizer production, distribution, marketing, and use in Pakistan. TVA, as well as other organizations, could be considered to make the study.

NFC Plant Facilities

The newly organized National Fertilizer Corporation was formed to take charge of all public sector fertilizer production facilities. These include the Pak-American plant at Daud Khel, the Natural Gas Fertilizer Factory at Multan, and the Lyallpur Chemicals and Fertilizers Ltd. with plants at Jaranwala and Lyallpur. Also NFC will control the proposed phosphate plant of the Pakistan Fertilizer Corporation (PFC). This plant (originally Jaffer Bros.) was planned for a Karachi location, but may now be shifted to Haripur to utilize indigenous phosphates. The Sarhad Development Authority (SDA) has been formed as a joint venture of the Northwest Frontier Province (NWFP) with NFC to produce phosphoric acid (80,000 to 90,000 tons of P_2O_5/year). Most of this acid would be supplied to the proposed adjacent PFC plant to produce monoammonium phosphate or other phosphatic fertilizers. The remainder would be used by SDA to make triple

superphosphate (TSP) or other phosphatic fertilizers. There are plans for construction of a small urea-ammonia plant by the Peoples Republic of China in the Hazara District which could be a source of ammonia and/or urea for use in the PFC plant. Also SDA has requested that the Ammopac plant now at Multan be transferred to SDA to supply ammonia for ammonium phosphate production.

A Multan Fertilizer Expansion Project has been approved which will include a 910 ~~tpd~~ mt/day* ammonia plant with facilities for producing 1020 ~~tpd~~ mt/day of nitrophosphate (22.5-22.5-0), 150 ~~tpd~~ mt/day of ANL or CAN (26% N) and about 220 ~~tpd~~ mt/day of urea.** The expanded plant will be operated by a new company, Pakarab Fertilizers Ltd. (PFL) under the direction of NFC.

Interviews and Visits

The principal interviews and visits made by the TVA team are listed chronologically:

1) Interviews with NFC and Chemical Consultants in Lahore.

2) Meeting with Dawood-Hercules personnel in Lahore (regarding utilization of excess ammonia available from the DH plant for either direct application or for treatment of single superphosphate to improve its physical properties).

3) Inspection of Jaranwala and Lyallpur superphosphate plants and discussion of problems with staff.

4) An informal seminar in which the team presented current and projected world market conditions and economics of fertilizer raw materials and products (mainly by slides) to a group of 30-40 NFC and other personnel at Lahore. The presentation was followed by a lively discussion.

~~All tonnage figures in this report are metric tons.~~

*For details, see Report No. 373-PAK "Pakistan: Appraisal of Multan Fertilizer Expansion Project" April 3, 1974, a document of the International Bank for Reconstruction and Development, International Development Association.

5) Inspection of the Pak-American plant and gypsum mine at Daud Khel and discussion of plans and problems.

6) Interview with Sarhad Development Authority (SDA) personnel at Peshawar concerning phosphate deposits.

7) Inspection of proposed SDA plant sites near Haripur and one of the phosphate mine sites near Abbottabad (Kakul) and discussion at Abbottabad with representatives of NFC, Pakistan Mining and Minerals Company and others.

8) Various consultations with AID staff.

9) Review of results of the team's study with Babar Ali and other NFC staff.

Interview with Dawood-Hercules

The recently completed Dawood-Hercules plant near Lahore is operating at full capacity (about 600 mt/day of ammonia and 1,000 mt/day of urea). However, the ammonia plant has excess capacity estimated at 3,000 to 5,000 tons/year which cannot be utilized at the plant because the urea plant does not have equivalent excess capacity. The interview with D-H personnel was for the purpose of exploring the possibility of utilizing this ammonia for direct application to the soil or in irrigation water. To minimize capital investment, it was suggested that the ammonia be converted to a nonpressure solution, either aqua ammonia (20% N) or urea-ammonia solution (30-33% N).

It was pointed out that ammonia costs much less than urea per unit of nitrogen, so its utilization should be economically attractive and has proven so in several countries (U.S., Mexico, and Denmark, for instance). Injection of anhydrous or aqua ammonia in irrigation water is a method used in California and Mexico. Since most of Pakistan's fertiliser use is on irrigated land, this method might be the most convenient.

In the United States, the average price paid by farmers in 1970 for various nitrogen fertilizers was:

	$/kg of N
Anhydrous ammonia	0.10
Urea	0.20
Ammonium nitrate	0.20
Urea-ammonium nitrate solution	0.19
Ammonium sulfate	0.28

The prices given above do not include application cost; for custom application a typical charge is $1.75/acre for anhydrous ammonia and $0.75/acre for solid fertilizers. This is equivalent to $0.026/kg of N for ammonia and $0.006 for solid nitrogen materials assuming an application rate of 100 lbs. of N/acre. It is recognized that these figures are not applicable to Pakistan; methods of distribution and application that would be best suited to Pakistan conditions would need to be developed. (Also, U.S. and world prices for nitrogen have soared in the past two years.)

Dawood-Hercules personnel were not enthusiastic about the project because of capital and development expenses. However, they were willing to undertake it if financial and technical assistance were available from TVA, USAID, or other sources. They requested that we send them information about preparation of the solutions, methods, and equipment for transport and application, and agronomic results.

In contrast to the unenthusiastic attitude of Dawood-Hercules personnel, several members of the NFC staff expressed a keen interest in promoting liquid nitrogen use (in subsequent interviews.)

Natural Gas Fertilizer Factory (Multan)
Mr. Hafizulla, General Manager

Fertilizer products made at Multan are ammonium nitrate-limestone (ANL-26% N) and crystalline urea. ANL is produced by the St. Gobain process: Ammonium nitrate solution is sprayed from a spray pipe on a rolling bed in a drum granulator. Recycled product and ground limestone enter the feed end. There is no retaining ring at the discharge end. The spray pipe extends most of the length of the granulator. From the granulator, the product goes to a drier. After drying, the product is screened; fines and crushed oversize are recycled and product size is cooled and conditioned with kieselguhr. The product quality seemed very good.

Urea is produced by the Inventa process. The product is crystallized, centrifuged, and dried. The urea is quite small in particle size and caking is a problem. The crystals are bagged in cotton bags. A prilling tower is under construction.

The capacities of the ANL and urea plants are 300 and 220 tons/day, respectively. This is somewhat above the rated capacity, especially for the urea plant. However, the ammonia supply is insufficient to operate these plants at capacity.

The original ammonia plant, built in 1962, was supplied by Grand Paroisse (French) and uses the Casale process. The rated capacity was 200 tons/day, but the actual present capacity is about 150 tons/day. The reduced capacity is due to two factors: (1) Cooling of the gas leaving the ammonia synthesis unit is inadequate, with the result that ammonia condensation is inefficient, and the gas recycled to the synthesis unit contains 5% ammonia. This decreases conversion efficiency.

(2) The plant was designed to operate at 600 kg/cm^2 (about 8,500 lbs/in^2) but due to excessive maintenance at that pressure, it is operated at 500 kg/cm^2 (about 7,000 lb/in^2). There were still some compressor problems at that pressure, but they were not considered excessive.

To make up the deficit in ammonia supply, an Ammopac unit was installed by Girdler in 1968, rated at 60 ~~tons~~ mt/day of ammonia. This unit has not operated satisfactorily; it produces only about 40 ~~tons~~ mt/day when it runs, and is often shut down for compressor maintenance. There were originally two compressor units; Girdler supplied a third for use as a spare. The compressors are driven by internal combustion gas engines. Compressors and gas engines were supplied by Thomasson (Dutch). At NFC offices, we were told that the gas engines did not operate satisfactorily; however, the plant manager at Multan indicated that the main trouble was with the compressors. During our visit, two compressors were down for repairs and the third was idle. It appeared that the current practice was to keep two of the compressors in operating condition and the idle compressor was not in operable condition.

The plans are to scrap the older plant when the new (910 ~~tons~~ mt/day) ammonia plant is built. The Ammopac plant will either be scrapped or transferred to the Sarhad Development Authority for use in the proposed phosphate plant near Haripur to supply ammonia for ammonium phosphate. The new plant is scheduled for completion in three years but because of shortage of construction materials and fabrication facilities, the schedule may not be met. So any expenditures on the old plant would have to be amortized in three to four years. Since Pakistan is now importing urea at some $100/ton and ammonia can be made at low cost with $0.30/MMBtu gas, any near-term increase in production would be very much worthwhile.

If ammonia production could be increased to match the capacity of the downstream plants, the additional production of nitrogen fertilizers would be worth $8 to $14 million/year at current import prices. The rated capacity of the urea and ANL units is equivalent to about 56,000 ~~tons~~ mt of N/year, whereas actual production has ranged from 43,600 in 1969-70 to 24,000 in 1972-73. If the shortfall is made up by importing urea at $300/ton ($655/ton of N) the annual cost will be $8 to $14 million.

The new plant is designed to produce 1,020 ~~tons~~ mt/day of prilled nitrophosphate, 22.5-22.5-0 with 80% of the P_2O_5 water soluble. The nitrophosphate process will be supplied by Stamicarbon. It will also produce 1,500 ~~tons~~ mt/day of granular ANL (26% N), partly as a byproduct of the nitrophosphate process, and partly by direct neutralization of nitric acid. Two 600 ~~ton~~ mt/day nitric acid plants will be built and the present 200 ~~tons~~ mt/day unit will be retained. Concentration of the acid will be 57%-60% HNO_3. Fellogg and Uhde are the contractors.

The present ANL and urea units will be retained. As mentioned previously, the urea will be prilled. We asked why they planned to make ANL instead of straight ammonium nitrate. We were told that there were plans to make prilled straight ammonium nitrate. However, such plans are not mentioned in the IBRD report.

Pak-American Fertilizer Ltd.
Mr. Sherwani, General Manager

The Pak-American plant at Daud Khel near Mianwali on the Indus river is the first fertilizer plant built in Pakistan. It was built in 1957-58 by Union Chemique Belge.

The original plant utilized coal from a nearby mine as ammonia feedstock. The coal gasification process utilized lump coal which was gasified by a mixture of steam and oxygen in Lurgi-type gasifiers. The coal was low grade, containing up to 30% ash and up to 6% S. When natural gas became available, the plant was converted to use of gas, using a partial oxidation process. Later, a second unit was added to produce synthesis gas by steam reforming of natural gas. The gas from the two units, after CO shift conversion, goes into a common train for further purification and ammonia synthesis. The total ammonia production capacity is about 80 tons/day.

Primary CO_2 removal from the synthesis gas is by scrubbing with aqua ammonia, producing ammonium carbonate solution, which is used to make ammonium sulfate by reaction with gypsum. The reaction is carried out with an excess of ammonia which is later neutralized with sulfuric acid. The ammonium sulfate solution is separated from byproduct calcium carbonate with rotary drum filters. The solution is evaporated and crystallized and the crystals are recovered by centrifuging. The crystals are dried and packaged in cotton bags. The crystals were of a block shape and fairly large, but not as large as that sold in the United States for direct application or bulk blending. The by-product, calcium carbonate, was slurried and disposed of in a pond. Some of it was utilized by a nearby cement factory.

The plant was said to be operating above design capacity, which would be about 100,000 ~~tons~~ mt/year of ammonium sulfate ~~per year~~. However, records showed that annual production in recent years was about 60,000 ~~tons~~ mt. The shortfall was partly accounted for by diversion of some of the ammonia to refrigeration and national defense uses.

We visited the nearby gypsum mine where an entire hill consisted of gypsum with a few veins of dolomite. The one hill was said to contain 35 million ~~tons~~ mt of gypsum. Below the gypsum was anhydrite. Mining was evidently quite inexpensive.

The fertilizer plant was well built and maintained. Excellent shop maintenance facilities were available. There was a 20 tons/day sulfuric acid plant and a larger one was planned for production of superphosphate. In view of the high cost of sulfur ($120/ton at Karachi plus rail frieght), the manager proposed to recover most of the excess ammonia from the ammonium sulfate solution after calcium carbonate separation by thermal decomposition rather than neutralizing it with sulfuric acid. Equipment for this modification would be constructed in the shops at Daud Khel.

Laboratory tests were in progress of the use of Hazara rock (32% P_2O_5) for single superphosphate. We did not have an opportunity to talk to the men who did the work. The manager told us that when the required amount of sulfuric acid was mixed with the rock, the mixture was fluid for an hour or two. (In normal circumstances, the mixture should solidify in about 2 minutes.) Better results were obtained by adding the acid in increments. The best concentration of sulfuric acid was said to be 66% H_2SO_4. The highest water-soluble P_2O_5 content in the product was 17.5%. Free acid content was quite high. It appeared that no attempt was made to simulate deaning and curing conditions by conserving

heat of reaction or by preventing loss of moisture during curing. TVA's procedure for laboratory-scale tests of superphosphate production has been sent to Mr. Barber Ali.

The company carried out some other enterprises in addition to fertilizer manufacture. One of these was penicillin production; we were given a tour of the penicillin plant.

Lyallpur Fertilizers & Chemicals Ltd.
Mr. Syed Shahabuddin Ahmed, General Manager

The company has two superphosphate plants located at Lyallpur and Jaranwala, about 20 miles apart. The first plant was built at Lyallpur. This location was not considered suitable for expansion because of limited space and a local tax situation, so the second plant was built at Jaranwala.

The Jaranwala plant has a Moritz-Standaert den; the capacity is 240 ~~tons~~ mt/day on a 24-hour basis. At present, the sulfuric acid production capacity is 50 ~~tons~~ mt/day which limits annual superphosphate capacity to 32,000 tons. A second sulfuric acid plant was under construction which would double the capacity. (Pakistan is capable of constructing its own sulfuric acid plants.) The Lyallpur plant has a 20 ~~tons~~ mt/day sulfuric acid plant and a small Moritz-Standaert den; the annual superphosphate capacity is 10,000 tons. Both plants were shut down for lack of sulfur and had been out of sulfur for 2½ months in one plant and 4 months in the other. (Some other government agency was responsible for procurement of imported materials.)

A substantial quantity of Jordan phosphate rock was on hand at both plants. It was stored in the open, piled on the ground on either side of the railroad spur. The rock is quite fine, and it was evident that

the wind had blown some of it to adjacent areas. High winds and dust storms are not uncommon. Possibly there may be considerable loss by wind and other scattering. A shed with brick walls was under construction for covered storage of at least part of the rock. The manager said this was to keep it dry; during wet weather the moisture content of the rock was up to 3% which made grinding difficult.

There was a large, concrete superphosphate storage building at Jaranwala. The superphosphate removed from the den by a short conveyor belt, then to storage curing by payloader. When cured, the superphosphate was moved to a disintegrating mill by payloader then to a hopper and bagging machine. There was not much superphosphate in storage; it appeared to be quite dry and friable. It was said to contain 19% to 20% water soluble P_2O_5.

Other than lack of sulfur, the principal problem seemed to be bag rot (cotton bags). Woven polypropylene bags had been considered but rejected because of high cost (they would have to be imported). Plastic film liners had been tried and were effective as long as all bags in a shipment were intact. When one bag bursts, adjacent bags are weakened by attack of the cotton exterior bags. The present solution was to spray the cotton bags with 10% sodium carbonate solution. This caused the bags to shrink so larger bags were necessary.

It was recognized that the cause of bag rot was free acid in the superphosphate, (probably gaseous fluorine compounds generated by the free acid). The staff was reluctant to consider neutralization of free acid by ammoniation or addition of ground limestore or dolomite because it would lower the water-soluble P_2O_5 content. The product is sold on the basis of its water soluble P_2O_5.

The bag rot problem was discussed with a superphosphate manufacturer in the Netherlands. It was their experience that bag rot (jute bags) was minimized by keeping the ratio of moisture to free acid above 2. Typical analysis of granular product to storage was 6.0% moisture (weight loss after drying 3 hours at 100°C) was 1.2% free acid P_2O_5. The company had no experience with cotton bags.

Granulation was discussed; space was available in the manufacturing building for a granulation unit. After granulation, coating the granules with about 2% of ground limestone or dolomite probably would be sufficient to control bag rot with minimum loss of water solubility. It is likely that granulation will be needed to improve the physical properties of the product; since nearly all other fertilizers soon will be granular, the farmers may not accept powdery materials much longer. The staff seemed to be in favor of granulation, and requested information on this subject, which has been supplied.

It has been noted that when Jordan rock was used, the superphosphate mixer blades corroded rapidly and had to be replaced frequently, probably due to the chloride content of this rock.

Some of the staff stated that gypsum was needed on Pakistan soils to correct problems of salinity or alkalinity, and therefore superphosphate was preferable to more concentrated fertilizers that did not contain calcium sulfate. In discussing this problem later with AID personnel, it was stated that there were salinity problems with only 10%-20% of cultivated soils, and that the quantity of gypsum in the usual application of superphosphate would not do much good.

Various figures were given for the cost of phosphate rock. At NFC we were told that Jordan rock was $35 to $37/ton C&F Karachi; Moroccan

rock was $50-$52. Elsewhere there was mention of a price increase to $50 for Jordan rock (32% P_2O_5). The IBRD report (April 1974) gives the cost of Jordan rock as $40 at Karachi and $46 delivered at Multan.

A plant test of the use of Hazara rock had been carried out at Lyallpur with disappointing results (14%-15% water soluble P_2O_5). The low grade of the rock (28% P_2O_5) and its low reactivity were probably causes.

Indigenous Phosphate Rock

This section of the report deals with information collected by the team from reports, interviews, and field trips. Appendix II gives the results of characterization studies of phosphate rock samples received by TVA after the team's visit.

A report* dated June 1973 by Chemical Consultants Ltd. (CCL) gives detailed information about the geology and character of the Hazara District phosphate deposits. Some 15 phosphate occurrences have been noted in the Northwest Frontier Province, but only (2) or (3) have been studied in any detail as far as we know. Prospecting and experimental mining have been concentrated on two areas; the Kakul-Mirpur area about 5 miles from Abbottabad, and the Lagerban area about 25 miles north of Abbottabad. The CCL report summarizes reserves (in millions of tons) as follows:

	Proven	Probable	Potential
Lagerban	2.5	2.0	
Mirpur Kakul	1.4	0.6	
Other Abbottabad area	- -	- -	12.0
Tarbela	- -	- -	5.0
Total	3.9	2.6	17.0

*Extract from report entitled "Production of Phosphatic Fertilizers in the N.W.F.P.", Chemical Consultants (Pakistan) Ltd., June 1973

Of the proven reserves, the CCL report classifies 1.7 million tons as high grade, averaging 30% P_2O_5 and easily upgradable to 32%-34% P_2O_5. The greater part of the reserves contain silica as the major impurity, but the Kakul area, dolomite was said to be the major impurity. However, lump samples picked up by the team at the mine near Kakul contained some siliceous impurity but no dolomite. Also, a composite sample from seven pits in the Kakul hill area was found to contain silica as the major impurity. No beneficiation tests were reported, but one report states that the silicic types can be readily beneficiated by a simple process. The report estimates mining costs at Lagerban or Mirpur-Kakul at 150 rupees/ton (about $15), including transportation to a plant site near Tarbela. Detailed chemical analyses of high and low grade rock show no unusual impurities.

A later (undated) document*, probably issued some time in the spring of 1974, states that "already reserves of about 10 million tons (mainly high grade) have been proven and probable reserves appear to be much greater." The lower grade rock was said to be "easily upgraded by a simple gravity separation."

Prospective contractors were told to base their design on a phosphate rock cost of 300 rupees/ton (about $30) delivered to the plant site and on the following analyses:

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*Tender Specifications: Phosphate Fertilizer Plant in N.W.F.P. (issued by EDA, prepared by CCL)

	Medium Grade (For Phosphoric Acid Production)		Higher Grade For TSP
	Mirpur-Kakul	Lagerban	Mirpur
P_2O_5	33.1	32.0	34.5
F	3.4	3.3	3.6
SO_4	1.2	0.7	1.1
CO_2	4.2	4.5	4.0
CaO	52.0	45.5	50.8
MgO	2.0	1.6	1.3
Al_2O_3	0.9	0.5	0.8
Fe_2O_3	1.5	2.9	1.5
SiO_2	2.3	8.5	2.3
Na_2O	0.3	0.25	0.3
K_2O	0.2	0.15	0.2
Cl	0.02	0.02	0.02

Another report by C. R. Meissner of the U.S. Geological Survey* (marked received 2/9/66), describes results of a survey in an area between Kohat and Attock. Occurrences of phosphate rock contained 5% to 15% P_2O_5. The report recommends further exploration which apparently was not done.

Ownership and control of the phosphate deposits appear to be quite complex. Apparently mineral rights are vested in the provincial government (NWFP in this case). However, mineral deposits that are vital to the country can be nationalized. If the rock is mined, property owners must be compensated for the value of their land. NWFP through SDA has given short-term leases on several tracts to private sector organizations for exploration purposes. Of these, United Minerals (Lagerban area) and Pakistan Mining (Mirpur-Kakul area) appear to have been the most active. No leases permitting commercial mining are known to have been given.

SDA officials told us that some 9 million tons of proven reserves had been reported in the Lagerban area by a United Mineral geologist. The report was verbal and no hard data was available to support the claim.

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*Technical letter "Phosphatic Rock in the Nizampur Area of the Kala Chitta Hills." C. R. Meissner

It is not known whether core drilling had been done or what the basis for the estimate may have been. The Lagerban area is at present unaccessible to vehicular approach.

It seems likely that several organizations are competing to gain contracts or leases, and may regard their information as confidential. The private mining organizations apparently are conducting exploratory mining with their own funds. Naturally they cannot afford large expenditures when there is no assurance that they will receive contracts or leases for commercial mining. Also, if they are given permission to mine the rock, it appears that their only customers would be government corporations, the NFC plants or the proposed SDA plant jointly owned by NWFP and NFC.

The team visited the Kakul mining area accompanied by representatives of NFC and Pakistan Mining & Minerals Corporation. Exploratory mining was proceeding at seven locations on Kakul Hill (elevation is about 4,900 ft.). The site visited was designated as the No. 3 mine. Figure 1 is a photograph of the mining site that was visited. Some substantial amount of ore had been mined and stacked upon a ledge (perhaps 50 tons). At present, the only means of transporting the ore is by donkey. A dry weather jeep road has been cut to the base of the hill. Another road is planned for truck access, but a bridge would be required; the short-term lease does not seem to justify this expense. A core drilling rig had been brought in but not set up.

Based on the team's very limited observation, it would seem that only a small percentage of the ore in this area could be mined by primitive, surface mining methods. However, this small percentage might be a substantial quantity, perhaps in the order of 100,000 tons. This is a very rough guess, and it should be noted that neither of the team members have

mining experience. However, it seems evident that underground mining will be necessary to extract the ore beyond that available by surface mining.

The CCL report mentions several other occurrences in Hazara including a 50-foot thick phosphorite zone near Tarbela, but no further information was available.

Fertilizer Production and Consumption Estimates

Present and planned fertilizer manufacturing facilities and their rated (or proposed) capacities are summarized in table I. Of the six new or expanded facilities, only two have been contracted for and there is more or less doubt about the other four. This situation makes forecasts of production difficult. However, forecasts of production have been made and compared with estimated demand in table II. The production forecasts are based on the assumptions stated below the table.

These assumptions include some increase in production from present facilities, completion of the new Multan plant and the Jaranwala expansion on schedule, and a decision to build the Fauji ammonia-urea plant and the Sarhad/PFC phosphate complex with schedules indicated in table II. Other proposed projects are not included because plans seemed vague.

It will be noted that the estimated production of both nitrogen and phosphate fertilizers are substantially less than forecast demand, indicating a need for continued substantial imports if consumption estimates are correct.

Table I

Summary of Present and Planned Fertilizer Production Facilities in Pakistan

Company	Location Present Plants	Product	Rated Capacity tons of nutrient/year N	Rated Capacity tons of nutrient/year P_2O_5	Date on stream
NFC	Daud Khel	Ammonium Sulfate	20,000[a]	1958	
NFC	Multan	ANL urea	26,000 30,000		1962
NFC	Lyallpur & Jaranwala	SSP		6,700[b]	1957
Dawood Hercules	Lahore	urea	155,000		1972
Esso	Daharki	urea	78,000		1968
Plants Proposed or Under Construction, Including Expansions					
NFC	Lyallpur & Jaranwala	SSP	5,800[c]		1975
NFC	Multan	Nitrophosphate ANL urea	70,000 138,000[d] 37,000[d]	70,000	1977-78
NFC	Daud Khel	SSP		Indefinite	
Fauji		urea	240,000		Indefinite
Sarhad	Hazara	TSP/MAP		90,000	Indefinite
Chinese	Hazara	urea	33,000		Indefinite

[a]Diversion of ammonia to refrigeration and defense uses limits ammonium sulfate production to levels below capacity
[b]Present capacity based on available sulfuric acid capacity
[c]Additional capacity equivalent to increased sulfuric acid capacity
[d]Total capacity after expansion

Table II

Past and Forecast Consumption of Production Of Fertilizers in West Pakistan (Thousands of Metric Tons of Nutrient)

	N			P_2O_5			K_2O
Year*	Consumption	Production	Deficit	Consumption	Production	Deficit	Consumption
1966	69	47	22	1.2	1.4	0.0	-
1967	108	52	56	3.9	0.7	3.2	0.14
1968	177	50	127	12.8	2.9	9.9	0.21
1969	203	79	124	38.6	2.5	36.1	2.50
1970	253	129	124	33.8	4.0	29.8	1.34
1971	272	130	142	30.5	4.6	26.0	1.22
1972	344	215	129	37.2	5.0	32.2	0.74
1973	386	254	132	48.7	5.0	40.7	0.50
1974	430	281	149	60	6	54	10
1975	475	290	185	73	9	64	15
1976	530	292	238	90	12	78	20
1977	590	346	244	108	38	70	25
1978	650	551	99	130	70	60	30
1979	720	678	42	155	103	52	35
1980	790	697	93	185	137	48	40
1981	875	697	178	220	156	64	45

*Year ending June 30 of indicated year -- Data for 1973 are preliminary - Forecasts are for 1974 and following years.

Assumptions: Esso and Dawood-Hercules will operate at 100% annual capacity. Daud Khel ammonium sulfate plant will be brought up to 95% capacity by 1976. Present Multan facilities will contribute 43,000 tons of N/year through 1976. New Multan facilities will start onstream late in 1977 and will operate at 90% capacity in 1979 and thereafter. The proposed Fauji Foundation ammonia-urea plant (or similar plant) will start operating in 1978 and reach 90% capacity in 1980. The Lyallpur/Jaranwala superphosphate plants will operate at 90% capacity, and the expansion will be completed in 1975 and fully effective in 1976. The proposed SDA/PFC complex will start late in 1977 and reach 90% capacity in 1981. Other proposed plants are not considered.

Observations: Distribution and Marketing

The primary objective of the team was to identify problems limiting fertilizer production in Pakistan, suggesting means for increasing production, and assist with longer range planning of additional fertilizer facilities. This objective lead to a limited exposure in the areas of distribution and marketing. Time was the limiting factor and precluded an in-depth study in distribution and marketing.

Most of the information was gathered from available reports and limited personal discussion with personnel in the areas of distribution and marketing.

The primary sources of published information came from the following:

1) Pakistan Fertilizer Situation - USAID Mission to Pakistan January 1974

2) Seminar in Prices of Agricultural Capital Inputs in Pakistan - Pakistan Institute of Development Economics - Islamabad - November 30, 1973

3) Fertilizer Marketing in Pakistan - by Changez Shuja - Dawood-Hercules Chemicals Ltd.

4) Journal of the Pakistan Institute of Chemical Engineers - Vol. 1 July-December 1973 - No. 1 and 2

5) Fertilizer Marketing and Distribution in West Pakistan - prepared for USAID Mission Pakistan by Chemical Consultants (Pakistan) Limited, Lahore August 1970

It is obvious that great emphasis is being placed upon the increased indigenous production and imports of raw materials for manufacture of fertilizers at this time to satisfy the presently established markets for fertilizer materials. This has been precipitated by the fact that prices have increased three to four times or more on specific items since 1970. However, particularly in the public sector, no short- or long-range

plans were evident for management and marketing of either indigenous production or imported materials. The private sector is well established and organized in this respect to cope with present and future problems. It is also quite obvious that the entrance of the private sector (Esso and Dawood-Hercules) in production and marketing in Pakistan has dramatically increased the supply and demand for fertilizer materials. Much of this success has been accomplished under unusual and difficult situations and problems.

With the new production facilities and anticipated expansion of present facilities, it becomes of paramount importance that management, administrative, and marketing programs be developed on a well organized and timely basis.

We understand that the present arrangement provides that the central government will allocate fertilizer supplies to the four provinces. The two private sector organizations will be permitted to market their products in specified areas. Fertilizer produced by NFC plants and imported fertilizers will be marketed by provincial government organizations.

Some of the literature indicated that several hundred people would be employed in the public sector (provincial) marketing program. However, no information was found as to the necessity for these people or the basic qualifications mandatory to perform the functions expected of them.

A personal, brief discussion with some of the marketing people indicated that many new employees had little experience and others had some basic agricultural experience in the geographic area or close

relationships with the distributor, dealer, or agent. The training received by these new candidates has been minimal and at times completely void. In many cases the extent of the training has been to travel with a representative for a period of two or three weeks.

For the public sector to be competitive and be able to successfully move the quantitites of fertilizer indicated, employees may require training in the areas of agronomy, soils, marketing concepts, sales or sales management, market planning, product knowledge, organization and conducting educational/sales meetings, advertising, sales promotion, credit, pricing strategy, assisting his customers in maximizing profits, planning distribution and storage, etc.

The private sector in Pakistan has focused heavily on training their personnel in marketing. A great amount of their success must be attributed to this effort.

At present, the most serious problem is the lack of sufficient fertilizer. In the future more problems may arise in distribution and marketing. Using Multan as an example, the new plant will produce well over 800,000 tons of products/year. In addition, at least 200,000 tons of phosphate rock will have to be moved to the plant. Expansions are also proposed at Daud Khel, Lyallpur, and the Haripur area. With the proposed expansion and present facilities, the inputs into the plants and outputs will be in the area of 2 million tons/year. Innovation, imagination, and initiative on the part of the individuals responsible will be required to insure timely delivery of raw materials to the plants and of fertilizer products to farmers.

Recommendations for NFC

1) A centralized procurement and distribution group should be established to manage, coordinate, and expedite rail, truck, and water transportation of all raw materials and products for NFC plants. Its purpose would be to provide timely, efficient delivery of raw materials to the plants and of fertilizer products to retail outlets. The manager of this group should be capable of planning the entire logistics program including regional and local storage requirements. He should be well acquainted with political and bureaucratic channels to expedite his performance.

2) The procurement and distribution group should work closely with the Trading Corporation of Pakistan for procurement of imported materials. Alternatively, (and preferably) NFC should be authorized to deal directly with suppliers of imported raw materials.

3) In the present system of provincial control of marketing, NFC must work closely with the provincial marketing organizations to achieve an orderly, efficient distribution system. A recommended alternative is that NFC should market its own products to eliminate duplication of effort and personnel. The present decentralized marketing system is likely to involve many problems in coordination of production, inventories, transportation, storage, and cost control. Management, administration, and marketing are a team effort. When fragmented, serious problems are likely.

4) A well-trained marketing organization is important whether this organization is part of NFC, as recommended above, or a function of the provinces as at present. Promising individuals should be selected for extensive training after which they could act as instructors for training new personnel. If NFC markets its products, it should establish and train a marketing group which should work closely with the procurement and distribution group. If marketing is done by the provinces, there should be close coordination between NFC and provincial marketing personnel.

5) At some stage of developing the NFC organization, it may be advisable to have product managers who are entirely responsible for their specific production promotion, production coordination, allocations, and keeping management and field force constantly informed of the latest developments regarding specific products. This arrangement may become useful when new products, such as nitrophosphates are produced.

The team fully recognizes that these recommendations are not within the scope of the original and basic assignment. From our brief exposure to personnel, literature, and studies provided, we hope that some contribution will be made to make NFC a great success at an earlier date.

Conclusions and Recommendations Concerning Short-Term Problems

Superphosphate

Sulfur Supply - The present situation in which superphosphate plants are idle for several months at a time for lack of sulfur should be corrected. At present sulfur (and most other imported materials) are provided by the Trading Corporation of Pakistan, an agency of the central government. Preferably NFC should appoint a specialized procurement officer with responsibility for ensuring adequate, continuous supplies of raw materials at minimum cost. He should arrange contracts and expedite shipments through direct contact with suppliers and shippers. If necessary, the procurement officer could work with the Trading Corporation of Pakistan although independent procurement by NFC would seem preferable.

The present high price of sulfur delivered to Karachi is mainly due to high freight costs from such remote sources as Canada and Poland. Possibility of nearby sources such as Iran and Iraq should be evaluated. (After leaving Pakistan, Mr. Gopp ascertained that sulfur may be available from Iran.)

Phosphate Rock Supply - Jordan rock currently being used causes rapid corrosion of mixer blades due to its chloride content. While this is not a serious problem, some other kind of rock might be better and perhaps more economical. Nauru rock is one possibility. It is unusually high in

grade and would produce higher grade superphosphate. The economics of using rock from various sources should be evaluated with due regard to the grade of the rock and the product.

Bag Rot - Deterioration of bags is due to the free acid content of superphosphate. It can be prevented by neutralization of free acid with ammonia, ground limestone, or dolomite. However, each of these methods causes some loss of water solubility. It is suggested that superphosphate be sold on the basis of available (citrate soluble) P_2O_5 content rather than water soluble. However, since a high water soluble P_2O_5 content is agronomically desirable for alkaline soils, it should be specified that 75% or 80% of the available P_2O_5 should be water soluble. This would be in line with the planned nitrophosphate specifications. Control of the free acid content at a low level may be effective in minimizing bag rot. The free acid can be controlled by the ratio of sulfuric acid to phosphate rock. Further recommendations are discussed under "Granulation of Superphosphate."

Expansion of Superphosphate Production - The planned expansion of the Jaranwala plant seems appropriate. Production of superphosphate at Daud Khel also may be appropriate, since some of the necessary facilities are already available (grinding mills and sulfuric acid facilities).

Use of Indigenous Rock for Superphosphate - Whatever amount of indigenous rock can be mined in the near future could best be used for superphosphate production since the facilities are already available. The main problem is low reactivity of the rock. However, superphosphate is produced succuessfully from unreactive rock such Kola apatite in Finland and other countries.

Examination of rock samples (see appendix II) showed that the rock must be ground to 100 mesh to free phosphate pellets from their siliceous coating. However, finer grinding may be necessary to ensure a satisfactory rate of reaction in superphospahte production.

After leaving Pakistan, some information was obtained in Holland and from TVA files on methods for producing superphosphate from igneous apatite and on granulation of superphosphate. This information was sent to Mr. Barbar Ali of NFC, along with TVA's bench scale procedure for superphosphate production tests which simulates conditions in full scale operation. For production of superphosphate from igneous apatite mined in Sweden, high sulfuric acid temperature (70°C) and fine grinding (97% minus 90 microns, 42% minus 32 microns) was said to be desirable. Alternatively, the apatite could be used in admixture with a more reactive rock, such as Morocco or Jordan rock. A mixture of about three parts of Morocco rock with seven parts of Kola apatite was reported to be used in Finland. Information from South Africa also indicated that high acid temperature and fine grinding was necessary when using Phalaborwa apatite for making single superphosphate. The recommended particle size was 95% through 270 mesh (Tyler). Certain modifications of the grinding mills were required to attain this fineness and to avoid excessive abrasion of the equipment. Experience with igneous apatite does not necessarily apply to Hazara rock which may be somewhat more reactive and less abrasive than igneous apatite.

As the quantity of indigenous rock mined is unlikely to be sufficient to supply the entire needs of the superphosphate plants in the near future, consideration should be given to using a mixture of indigenous and imported rock. The more reactive imported rock would start the reaction and generate heat which would speed up the reaction of the indigenous rock.

<u>Granulation of Superphosphate</u> - Farmers are unlikely to be satisfied with non-granular superphosphate when granular products become more

widely available. It is recommended that facilities be installed for granulating superphosphate. This would also help solve the "bag rot" problem since granular superphosphate can be conditioned by coating the granules with ground limestone or dolomite to prevent bag rot with very little loss of water solubility. Calcined dolomite is especially effective. Only 1% or 2% is necessary.

In designing a granulation unit, the possibility of the eventual production of granular compound fertilizer should be considered. In addition to superphosphate, urea or ammonium nitrate and ammonium sulfate could be added. Ammoniating solutions plus sulfuric acid may be used. The compounds can be upgraded by adding a supplemental source of P_2O_5, such as monoammonium phosphate. Potash salts may be incorporated if needed.

Multan Problems

The problems with the Multan ammonia plants (described previously) must be viewed in the context of plans to scrap the plants when the new ammonia plant is built. Completion of the new plant is scheduled in about three years, but it is a common experience that construction falls behind schedule so ~~four~~ 4 years would be more likely. Any capital outlay would have to be amortized in ~~three~~ 3 to ~~four~~ 4 years.

The team members are not experts in the mechanical details of ammonia plant operation. It is recommended, therefore, that NFC obtain the services of qualified experts from TVA or some other organization for a period up to a month to recommend changes in equipment or maintenance procedures that effectively and economically increase production.

In the team's inexpert opinion it would seem that with three compressor units available at the Ammopac plant it should be possible to keep two of them running most of the time and at least one running all of the time except when other parts of the plant cause shutdowns. We received conflicting reports as to whether the gas engine drives caused any major difficulties.

Also, the economics of providing additional cooling for ammonia condensation and recovery should be evaluated for the larger ammonia plant.

Excess Ammonia Utilization

The 3,000 to 5,000 ton/year excess ammonia capacity that is available from Dawood-Hercules is a rather small quantity, but if utilized it would decrease importation of equivalent nitrogen fertilizers which at current prices cost about $2 to $3 million.

Three methods of utilizing the excess ammonia were considered. The first choice, on the basis of immediate effectiveness, is to transport the ammonia to Multan where there is excess capacity for converting it to urea and ANL. We understand that tank trucks may be available which are used for transporting LPG. These trucks can be used for transporting ammonia with minor changes. Any brass or other copper alloy valves or other fittings should be replaced with steel or stainless steel.

A second possibility is utilization for ammoniation of superphosphate. This has been discussed under superphosphate. It would involve some delay while providing equipment for preparation of ammoniating solution and equipment for using it at the superphosphate plant.

A third method would be utilization for direct application such as by producing aqua ammonia and applying it in irrigation water. We

believe this possibility should be pursued as an experimental and development program, and not specifically as a means for utilizing present excess ammonia capacity.

In view of the enthusiasm of NFC personnel for a liquid nitrogen program and the reluctance of Dawood-Hercules to undertake it, we suggest that the NFC be encouraged in this endeavor. It has excellent potential for reducing the cost of nitrogen fertilizer to the farmer. Also, it seems likely that there may be excess ammonia available from other plants in the future. For instance, in the new Multan plant any malfunctioning of downstream units would create an excess supply of ammonia.

Utilization of excess ammonia from Dawood-Hercules to supply nonagricultural needs (refrigeration and defense) should also be considered.

Development of Phosphate Rock Reserves

We believe that rapid development of indigenous phosphate rock is of the utmost importance to Pakistan's fertilizer industry and agriculture, and hence to the nation's economy. We fear that the present complicated and fragmented method of development with so many participating agencies will cause undue delays.

Access roads must be built and equipment purchased before mining can begin. Even a thorough job of exploration and proving of reserves cannot be done without substantial investment in roads and equipment. No private sector organization can afford such investment without a long-term lease of substantial reserves.

Recommendations - Mining of the most promising reserves should start immediately. As mentioned above, long-term leases will be necessary if this is done by the private sector. The amount that can be mined without sophisticated equipment may be relatively small, but it will be helpful

in supplying Pakistan's needs and generating capital for further improvements. At first only high grade rock may be used, but any lower grade rock that is mined concurrently should be stockpiled for later use.

Exploration should be intensified in all areas, including those not presently active. Whenever sufficient reserves are located, beneficiation tests should be carried out to define the economics of upgrading lower grade rock.

At appropriate times, Pakistan should arrange for consultants in exploration, mining, and beneficiation. Such consultants should have experience with U.S. Western States phosphate rock operations where the deposits are generally similar to those in Pakistan.

In due time consideration should be given to securing the services of an experienced mining company, especially when underground mining becomes necessary, provided that further exploration shows sufficient reserves to warrant such operations.

The team has not seen evidence of sufficient minable and usable reserves to justify construction of the plant proposed by the Sarhad Development Authority. However, assuming the conditions set forth in the Tender Specifications by SDA, such a plant would be economically feasible.*

We suggest that more emphasis be placed on beneficiation and less on finding high grade rock. Most of the world's major producers mine relatively low grade rock and beneficiate it. For instance, Florida rock as mined may be 15% to 20% P_2O_5, North Carolina about 20%, western rock 20% to 30% and in Brazil grades as low as 6% to 10% P_2O_5 are being successfully utilized.

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*Production of 90,000 tons/year of P_2O_5 as phosphoric acid, part sold to PFC, part converted to TSP or DAP; $30/ton cost of rock and $60/ton cost of sulfur, delivered to plant site near Haripur. Estimated production cost of TSP, about $100/ton bulk.

Tests of utilization of rock in various processes should be carri out when representative samples are available. The processes should includ nitrophosphate, phosphoric acid, DAP, TSP, and superphosphate.

The possibility of utilizing Hazara rock and electric power from the Tarbela Dam to produce phosphorus and phosphoric acid should be studied. The products would be useful for producing detergents, animal feed and food grade phosphates, and organophosphorus insecticides.

In the event that the phosphate reserves prove adequate, consideration should be given to increasing the scale of operation of the propo SDA-PFC complex with a view to supplying more of Pakistan's future needs and exporting some of the phosphate fertilizer products to Afghanistan and perha other nearby countries.

Recommendation for Long-Range Planning

A complete study should be made by TVA or other organization experienced in making fertilizer studies to provide a recommended program for expansion of fertilizer production and use in Pakistan. Such a study probably would require a team of three or four experts for a period of at least ~~two~~ 2 months, of which one 1 month should be spent in Pakistan. The team should include a fertilizer production technologist, an economist, a marketing and distribution analyst, and perhaps a mining engineer.

It would be very helpful if more information could be made available concerning indigenous phosphate rock before or during the team's visit. Access to the principal phosphate sites should be provided. Representative samples from the principal reserves should be provided for characterization and assessment of amenability to beneficiation processes. These should include samples from areas not now under active study. Preferably much of the work should be done before the team's visit.

The team should prepare a preliminary report prior to its visit to Pakistan, utilizing available information. This report will serve as a working document for discussion, expansion, and modification during the visit.

The scope of the team's work should include:

1) A complete study of marketing and distribution for the next decade.

2) A study of technical and economic factors involved in future production facilities including processes, scale of operations, choice of products, plant locations, and available raw materials.

3) Evaluation of export potentials for nitrogenous and phosphatic fertilizers.

4) Evaluation of indigenous raw materials and resources.

5) Direct application of anhydrous ammonia or other liquid nitrogen materials to the soil or to irrigation water.

6) Possibility of utilizing indigenous sulfur materials such as volcanic sulfur in Baluchistan or pyrites. The vast, easily mined gypsum and anhydrite deposits near Daud Khel suggest that production of sulfuric acid and cement may be economically feasible, with use of the sulfuric acid for phosphate fertilizer production. The future price and supply of sulfur on the world market will have a bearing on this study. However, the inland location of phosphate deposits and market area increases the delivered cost of sulfur and favors use of local materials.

7) Evaluation of the possibility of electric furnace production of phosphorus and phosphoric acid at Tarbela.

8) Evaluation of phosphate rocks for use in nitrophosphate processes. Jordan rock may cause corrosion due to chloride content. Hazara rock may also contain chlorides, and the silica content might require a silica separation step in the process. (These studies might be done by NFC or CCL).

9) Possible production of straight ammonium nitrate (34% N) rather than ANL (26% N) at Multan.

10) Recommendation of type of phosphate products; TSP, DAP, MAP, SSP, or compounds.

11) Assessment of agronomic needs for nitrogen, phosphorus, sulfur, potash, and correction of saline and alkaline soil conditions.

12) In the event that indigenous rock phosphate appears inadequate or uneconomical, evaluate the economics of production of phosphate fertilizers from imported raw material vs. imported intermediates (such as phosphoric acid) vs. importation of finished products.

APPENDIX I

Partial list of people who supplied information for the team's study:

Mr. S. Baber Ali, Chairman, National Fertilizer Corp.

Dr. A. K. Oureshi, Technical Director, National Fertilizer Corp.

Mr. Syed Shahabbin Ahmad, General Manager, Lyallpur Chemicals and Fertilizers Ltd.

Dr. Muhammad Ishaque, Lyallpur Chemicals and Fertilizers Ltd.

Mr. Hafizullah, General Manager, Natural Gas Fertilizer Factory

Mr. Lafar Iqbal, Chemical Engineer, Natural Gas Fertilizer Factory

Mr. Sherwani, General Manager, Pak-American Fertilizer Ltd.

Mr. Mohammad Nasir Butt, Assistant Chief Engineer, Pak-American Fertilizer Ltd.

Dr. Ahmad Shah Nawaz, Managing Director, Chemical Consultants (Pak) Ltd.

Mr. Changez Shuja, Marketing Manager, Dawood-Hercules Chemicals Ltd.

Dr. Waheed M. Butt, Development Manager, Dawood-Hercules Chemicals Ltd.

Mr. Mehmud Ahmed, Pakistan Mining and Minerals Corp.

Mr. Sultan Masood Kahn, Chairman, Sarhad Development Authority

Mr. Khalid Moktadullak, Technical Director, Sarhad Development Authority

Members of USAID Mission to Pakistan:

Mr. William A. Wollfer, Deputy Director

Dr. Richard R. Newberg, Deputy Director, Ag. Policy

Mr. Clarence Bell, Capital Development

Mr. James G. Unti, Agricultural Economist

Appendix II

CHARACTERIZATION OF PHOSPHATE ROCKS FROM THE HAZARA DISTRICT, MIRPUR AREA PAKISTAN

by

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Summary

We have completed the characterization study of two phosphate rocks from the Hazara District, Pakistan. These rocks are simple mixtures of about 80% apatite and 20% silica. The phosphate particles are cemented with and their surfaces are penetrated by silica cement. The silica cannot be removed by physical beneficiation. Floatation is not practical because of the strong bond between the silica and the phosphate. Fine grinding to liberate the silica from the phosphate would result in objectionable phosphate losses.

The data show that grinding the samples to -100 mesh is necessary if the apatite is to be extracted from the unbeneficiated rock to produce phosphoric acid. A preliminary calculation shows that a 44% P_2O_5 triple superphosphate can be prepared by mixing about 60% merchant-grade acid with 40% unbeneficiated rock.

The characterization of the apatites in the two rocks show that they have a low degree of carbonate for phosphate substitution and would not be recommended for use in direct application.

In a previous report (Characterization of Phosphate Rocks from the Hazara Area, Pakistan by G. H. McClellan, January 1971) three samples

submitted by M. C. Manderson (letter, M. C. Manderson to T. P. Hignett, December 16, 1970) from the Hazara Area, Pakistan, were described as having significantly different textural and mineralogical characteristics from the ones described in this report. More precise geographic and geologic descriptions of phosphate rock sample locations would contribute to a more meaningful evaluation of a phosphate deposit and help to prevent the possibility of conflicting interpretations.

Introduction

In his letter of June 7, 1974, to D. L. McCune, T. P. Hignett requested that a preliminary characterization be made of two phosphate rock samples which were sent to TVA by J. G. Unti, Agriculture Economics Adviser, Islamabad, Pakistan. Mr. Unti had received the samples from Dr. A. K. Qureshi, General Manager, National Fertilizer Corporation of Pakistan Limited. In Qureshi's letter of June 15, 1974, to Unti, no mention was made as to where the rocks were collected; however, tags inside the sample bags indicated that both rocks were from the Mirpur area in Pakistan. One sample was labeled as a channel sample and the other was labeled as a representative bulk sample. The purpose of studying these rocks was to determine their suitability for the production of phosphoric acid or triple superphosphate.

Each of the two phosphate rock samples from the Hazara District weighed about 4 kilograms. One was a channel sample (our reference No. MR-552) and the other was a representative bulk sample (MR-553). Later, we received a third sample (MR-556) of about 150 grams which was labeled as a composite from seven pits of the Kakul Hill Mines. It was suggested that we examine the rock to see if it was similar to the first two and,

if so, not to study it. X-ray and petrographic analyses showed that MR-556 had the same type of apatite as well as the same textural and mineralogical composite as MR-552 and MR-553. Kakul phosphate has been previously described as containing dolomite as a major impurity, but a careful petrographic examination of this rock showed that dolomite was not present. Since this rock was not significantly different from the Mirpur rocks, no further work was done on MR-556.

Mineralogical Characterization: The two phosphate rock samples have very simple and very similar mineralogical compositions. They essentially consist of apatite and silica which occurs in the form of quartz, chert, and chalcedony. The apatite content of both rocks is between 76% and 78% and the silica content is between 17% and 19%. Small amounts of clay, limonite and heavy minerals constitute the remainder of the samples.

Testing: Both rocks consist of pelletal apatite whose average size is about 0.5 mm. The pellets are cemented with silica which is in the form of chalcedony and chert. The cement forms an interconnecting network throughout the rock, thus, completely enclosing many of the apatite pellets. The chert and chalcedony not only wets but also penetrates the surfaces of the phosphate grains as characterized by the absence of a sharp contact between the two mineral phases. Massive chert also occurs in the rocks as lenses. This chert is estimated to comprise about 25% of the total silica content. It does not occur isolated from the apatite pellets but together with it, because the silica cement which binds the apatite pellets also binds the lenses of chert to the apatite; therefore, this chert cannot be feasibly separated from the apatite by physical or chemical beneficiation. Quartz, both detrital and authigenic, is present

between the apatite pellets. Most of the quartz is free, but a small percentage ($<$0.5% of total silica content) is occluded in the apatite.

Because the average particle size of the phosphate is 0.5 mm, the minimum crushing required for liberation is 32 mesh (0.5 mm) or finer. When the rocks were ground to -35 to +80 mesh, (0.3 mm average diameter), only about 10%-15% of the phosphate was soluble in H_2SO_4. The samples had to be ground to -100 mesh (0.15 mm) in order to assure a nearly complete extraction of the phosphate.

The ground phosphate particles characteristically retained portions of the chert matrix tightly bonded to their surfaces. Because of this tightly bonded condition, the prospects for releasing the pelletal apatite grains by grinding does not appear promising. Because of the softness and friability of the phosphate particles, overgrinding to release the silica should be avoided in all beneficiation steps if slime P_2O_5 losses are to be minimized. Similarly, the incomplete removal of silica from the surfaces of the phosphate pellets during grinding would make beneficiation by floatation impractical.

Characterization of the Apatite: Optical and x-ray examinations of the apatites in samples MR-552 and MR-553 showed them to be francolites with a low degree of substitution of carbonate for phosphate. The approximate compositions of the apatites were determined from the crystallographic unit-cell dimensions obtained by x-ray powder diffraction and from established correlations of these parameters with crystal chemical composition. The empirical compositions of the apatites as represented by the formula

$$Ca_{10-(a+b)}Na_aMg_b(PO_4)_{6-x}F_{0.4x}F_2$$

were derived from the x-ray data shown in the tabulation.

Sample	Unit-cell dimensions a	c
MR-552	9.360	6.889
MR-553	9.359	6.889

From statistical models correlating unit-cell parameters with apatite crystal chemical composition, the apatites in these samples can be shown to correspond approximately to the empirical formulas:

		Stoichiometric P_2O_5 content, %
MR-552	$Ca_{9\cdot87}Na_{0\cdot09}Mg_{0\cdot04}(PO_4)_{5\cdot61}(CO_3)_{0\cdot39}F_{2\cdot15}$	39.99
MR-553	$Ca_{9\cdot86}Na_{0\cdot10}Mg_{0\cdot04}(PO_4)_{5\cdot59}(CO_3)_{0\cdot41}F_{2\cdot16}$	39.84

Chemical Characterization of Ores: The chemical compositions of the two phosphate ores are shown in Table I. The ratio of the P_2O_5 content of the rock to that of the pure apatite is equal to the apatite content of the rock. The acid insoluble fraction is equal to the sum of the quartz,

TABLE I

Compositions of Pakistan Phosphate Ore

	Composition, % of ores	
	MR-552	MR-553
CaO	42.7	42.2
P_2O_5	31.0	30.3
CO_2	1.0	1.1
F	3.2	3.2
Na_2O	0.21	0.24
MgO	0.16	0.13
SiO_2	17.0	18.4
Al_2O_3	1.4	1.2
Fe_2O_3	1.0	0.8
K_2O	0.41	0.37
Total S	0.15	0.17
SO_4 S	Nil	Nil
Cl	0.02	0.03
Acid Insols	20.8	22.2
NAC sol. P_2O_5	2.5	2.6
% Apatite	77.5	76.1

chert and chalcedony plus the clay and limonite contents of the rock.

Comments: Mr. Hignett has indicated that Pakistan is interested in producing phosphoric acid or triple superphosphate from the phosphate deposits in the Hazara District. This report shows that these rocks should be amenable to the production of these fertilizer products. However, this may involve the utilization of some non-standard fertilizer technology.

These rocks consist of a mixture of acid-soluble phosphate and acid-insoluble gangue minerals. This simple mineralogical composition could be employed to advantage in the processing of this ore. It is possible, for example, that floatation may not be necessary before acidulation. In fact, floatation would be undesirable because of the intimate association between the apatite and the silica. Floatation of the silica would require fine grinding and would result in objectionably large losses of P_2O_5 as slimes. The small size of the apatite pellets and the penetration of silica into the phosphate particle surfaces would require that the rock be crushed to about -100 mesh before acidulation in order to assure the complete dissolution of the apatite.

Some preliminary tests have demonstrated that the P_2O_5 of the unbeneficiated rock is amenable to acid extraction and thus, that the ore, even without beneficiation, may be suitable for the production of wet-process acid. This would, of course, require that 20% more raw material be handled in the process, particularly during filtration. The addition of the silica to the filter cake could lower the capacity of the filters, but this is not expected to be a serious problem.

Assuming that all the phosphate in the rock is removable for acid production, as the test indicated, and accessible for preparation of triple

superphosphate processing, the possible grades of triple superphosphate (TSP) produced from these ores may be estimated. The chemical reaction usually is written

$$Ca_{10}(PO_4)_6F_2 + 14H_3PO_4 + 10H_2O \rightarrow 10Ca(H_2PO_4)_2.H_2O + 2HF \qquad (1)$$

and commercial TSP prepared with 54% P_2O_5 (merchant-grade) acid usually contains 44% to 47% P_2O_5 when cured. The mole ratio $CaO:P_2O_5$ in fluorapatite is 3.33, whereas in these Pakistani rocks the values are 3.50 and 3.54. On the basis of equation 1 and with corrections for the ratio $CaO:P_2O_5$ and for the dilution of the product by the SiO_2 in the ore, the superphosphates in the tabulation could be produced from the unbeneficiated ores.

Sample	Grams acid (54% P_2O_5)/ 100 grams rock	P_2O_5 content, %, of superphosphate
Channel	144	44.6
Bulk	144	44.3

Drying during denning might raise the grades of these superphosphates slightly. In all these acidulation mixtures, a slight (about 2%) excess of acid is used, as often occurs in commercial denning practice.

Because of the potential corrosion problem in processing ores containing substantial quantities of chloride and reports that rocks from the Hazara District have moderately high chloride contents, these rocks were analyzed to determine the level of chlorides present. The results (Table I) show that the channel sample contains 200 ppm chloride and the bulk sample contains 300 ppm. Chloride levels exceeding 200 ppm can cause significant corrosion in 316 stainless steel, however 317 stainless steel is usually acceptable for use with rocks containing up to 600 ppm of chloride. Thus the Hazara District phosphate rocks could present a potential corrosion problem during processing.

Because of the low degree of substitution of carbonate for phosphate which indicates low reactivity, these rocks have essentially no potential as direct application fertilizers. In a previous report entitled CHARACTERIZATION OF PHOSPHATE ROCKS FROM THE HAZARA AREA, WEST PAKISTAN (January 13, 1971), dolomite was reported to be present in significant quantities in three phosphate rocks from the Hazara area. Since the presence of silica cement was not mentioned in the report it evidently was not an important textural feature. These three rocks, which are apparently from the same area as the ones described in this report, are obviously quite different in their textural and mineralogical characteristics.

The explanation for these differences may be geological or simply a matter of sampling technique. The conclusion that precise geographic and geologic descriptions of phosphate rock sample locations are relevant to a meaningful evaluation of a deposit is unavoidable.