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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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UNITED NATIONS INDUSTRIAL
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CONSULTATION WITH GOVERNMENTS OF SELECTED COUNTRIES OF AFRICA, ASIA AND LATIN AMERICA FOR POSSIBLE UNIDO ASSISTANCE TO DEVELOP PHOSPHATE AND PHOSPHATE-BASED INDUSTRIES

RP/GLO/77/001

Project findings and recommendations

Based on the work of Indu G. Jhingran, mining consultancy expert

id.77-3926

Explanatory notes

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions.

The term "billion" signifies a thousand million.

References to "tons" are to metric tons, unless otherwise specified.

References to dollars ($) are to United States dollars, unless otherwise stated.

The following exchange rates are used in the conversion of country currencies to United States dollars:

Country	Currency	Exchange rate per US dollar during the period covered by the report
Chile	Chilean escudo (E^0)	18.36 (mean value)
Madagascar	Malagasy franc (FMG)	250.00
Mauritania	CFA franc (CFAF)	50.00
Peru	Sol (S)	70.93 (mean value)
Saudi Arabia	Saudi Arabian riyal (SRls)	3.52
Sri Lanka	Rupee (SRs)	8.88
United Republic of Tanzania	Shilling (TSh)	8.31

The following abbreviations are used in this report:

BDPI	Bureau de développement et de promotion industriels (Office of Industrial Development and Promotion)
BRGM	Bureau de recherches géologique et minerie (Office of Geological and Mining Research)
COFIDE	Corporación Financiera de Desarrollo (Development Financing Corporation)
DAP	Diammonium phosphate
ENADISMA	Empresa Nacional Adaro de Investigaciones Minerales (Adaro National Mineral Research Company)
ENCI	Empresa Nacional de Comercialización de Insumos (National Inputs Marketing Company)

IIG	Instituto de Investigaciones Geológicas (Geological Research Institute)
INGEOMIN	Instituto Geológico Minero (Geological Mining Institute)
LOI	Loss on ignition
NIDC	National Industrial Development Corporation
ROI	Return on investment
ROM	Run of mine
SNIM	Société nationale industrielle et minerie (National Industrial and Mining Company)
SOCHIF	Sociedad Chilena de Fertilizantes (Chilean Fertilizer Company)
SOFIM	Soiété française des Isles de Madagascar (French Madagasy Islands Company)
SOQUIMICH	Sociedad Química y Minera de Chile (Chilean Chemical and Mining Company)
SSP	Single superphosphate
STAMICO	State Mining Corporation
TFC	Tanzania Fertilizer Company
TISCO	Tanzania Industrial Studies and Consultancy Organization
TSP	Triple superphosphate
TVA	Tennessee Valley Authority

ABSTRACT

The objective of the project entitled "Consultations with Governments of selected countries of Africa, Asia and Latin America for possible UNIDO assistance to develop phosphate and phosphate-based industries" (RP/GLO/77/001) was to collect and analyse data on phosphate deposits and phosphate-based industries in various countries in order to assess their development possibilities in this field. The countries covered were Chile, Madagascar, Mauritania, Peru, Saudi Arabia, Sri Lanka, and Tanzania.

The three-month mission began in mid-January 1977. Some of the expert's main conclusions and recommendations are briefly summed up below.

The small size of the known phosphate deposits of Chile provides only limited scope for the development of Chile's fertilizer industry on the basis of indigenous resources.

Madagascar has sufficient phosphate deposits to meet the country's phosphate requirements over the next five years.

Although no phosphate deposits of commercial significance have yet been discovered in Mauritania, the regional dispersal pattern of phosphates in the western Sahara makes it highly likely that the country does have important reserves.

Peru has considerable rock phosphate deposits which could make it a major supplier of phosphates to the Andean countries and possibly to Asia.

Rock phosphate exploitation is given low priority in Saudi Arabia because of the unfavourable composition of the deposits, transport and water supply problems, and the fact that phosphates can be easily imported from neighbouring countries.

In Sri Lanka, deposits that could make the country self-sufficient in rock phosphates have been discovered and explored. Urgent follow-up action is required.

A comprehensive exploration programme should be carried out to discover new phosphate deposits in Tanzania, although the country's known reserves may be sufficient to cover its needs until the late nineteen-eighties.

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I. INTRODUCTION

The project entitled "Consultations with Governments of selected countries of Africa, Asia and Latin America for possible UNIDO assistance to develop phosphate and phosphate-based industries" (RP/GLO/77/001) covered the following countries: Chile, Madagascar, Mauritania, Peru, Saudi Arabia, Sri Lanka and Tanzania. A project budget of $19,300 was approved in January 1977, and the three-month mission began shortly thereafter.

The objectives of the mission were as follows:

(a) To collect data on the location, extent and composition of rock phosphate deposits;

(b) To establish what steps have already been taken or are envisaged by the governments of the countries concerned with regard to the commercial mining and utilization of the deposits;

(c) To hold consultations regarding possible UNIDO assistance to ensure the expeditious development of phosphate deposits;

(d) To collect information and explore possibilities of UNIDO assistance in the development of the phosphatic fertilizer industry in the countries concerned.

Meetings with the responsible officials in each country visited were arranged through the UNDP resident representatives, and a careful study was made of the available documentation.

In Chile meetings and discussions were held with fertilizer manufacturers and with officials of the government agency responsible for the exploration of phosphate deposits and for the co-ordination of scientific and technological research.

In Madagascar, detailed discussions were held with officials of the service géologique, the Bureau de developpement et de promotion industriels (BDPI), the Agronomy Division of the Centre de recherches agronomique et de developpement rural, and the Geological and Mining Service of the Ministry of Economy and Commerce. A senior official of the Planning Ministry was also consulted. All these agencies are involved in the development of phosphate deposits in the Malagasy Republic, a project to which the Government of Madagascar attaches very high priority.

In Mauritania, discussions were held with officials of the Société nationale industrielle et minerie (SNIM), the government agency responsible for developing Mauritania's rock phosphate deposits. Since work on phosphates is still at an early stage, it was not possible to collect much data.

In Peru discussions were held mainly with technical officers of Minero Peru, the Government agency which has done exhaustive work on phosphate deposits and which is now going ahead with the establishment of a fertilizer complex using concentrates to be produced from the rock phosphate reserves of the Sechura region. Officials of the Instituto Geológico Minero (INGEOMIN) provided geological data concerning the deposits. The Empressa Nacional de Comercialización de Insumos (ENCI) supplied important information regarding the import and consumption of fertilizers in Peru, and the Instituto Nacional de Planificación explained the drilling that will be necessary before investment for the project is cleared.

The expert visited both Riyadh, the capital of Saudi Arabia, and Jidda, where the office of the Director General of Mineral Resources and Institute of Applied Geology are located. Discussions were held with the Chief Technical Advisor and Head of the Economic Geology Division of the Institute of Applied Geology. A meeting was also arranged with the Deputy Governor of Petromin, which is responsible for the development of phosphate deposits in Saudi Arabia.

In Sri Lanka discussions were held with officials of the government departments and agencies responsible for the Eppawala carbonatite deposit, which was visited during the mission. Meetings arranged with the two state-owned fertilizer corporations also gave valuable insight into various aspects of the mission's field of interest.

In Tanzania detailed discussions were held with officials of government departments and agencies concerned with fertilizers and rock phosphate. Even though a visit to the Minjungu rock phosphate deposit could not be arranged, extensive literature on the subject was made available by the State Mining Corporation (STAMICO), which greatly contributed to a clearer understanding of the Minjungu reserves. Other valuable information was provided by the Tanzania Fertilizer Company (TFC) and the Tanzania Industrial Studies and Consultancy Organization (TISCO).

II. FINDINGS AND RECOMMENDATIONS

A. Chile

Considering the size of the country, the known phosphate deposits of Chile do not offer a bright future for the development of its fertilizer industries based on the indigenous phosphate resources. Until such time as new phosphorite horizons are discovered, Chile will have to continue importing rock phosphate, despite the present low level of phosphatic fertilizer consumption.

The biggest phosphate deposit of the country at Mejillones has an estimated reserve of 27,000,000 tons; the low P_2O_5 content (averaging 7%) makes this otherwise potential deposit less attractive for eventual exploitation. However, considering the fact that the Jacupiranga deposit of Brazil, with an almost identical P_2O_5 content, could be enriched to an acceptable grade for the phosphatic fertilizer industry, there is every reason why the Mejillones deposit should be given a fair trial. The following plan of action is suggested.

The services of a geologist experienced in rock phosphate exploration are needed to draw up a well-defined exploration programme with a precise timetable, and to ensure its implementation according to schedule. Since Chile does not make drilling equipment for prospecting, the possibility of using some of the copper and metallurgical equipment will have to be seriously considered in order to save foreign exchange. The Government will have to take a decision regarding the expeditious development of indigenous raw materials, particularly those falling outside the current foreign-exchange-earning sector. Although the P_2O_5 values of Mejillones are low, it is worthwhile exploring whether this rock can be floated to the stipulated grade for the manufacture of phosphoric acid with by-product suphuric acid available from the neighbouring Chuquicamata copper smelter. From the analysis undertaken it may be noted that the unbalanced ratios between P_2O_5 and CaO with high concentration of Na may be suggestive of some structural substitution of Na in crystal lattice of phosphate. This needs thorough minerological examination of the phosphate rocks of the Mejillones area.

B. Madagascar

The guano deposits of the Barren Islands have an estimated reserve of about one million tons only. In view, however, of the small requirement of phosphates in Madagascar, it should be possible to eliminate the use of imported rock by changing the supply sources to the Barren Islands. Since exploitation of the deposits involves scrapping and subsequent shipping to the mainland for processing, a word of caution is necessary in planning the logistics. As regards their use, it would be advisable to go through the direct application route in view of the probably higher water solubility; the processed fertilizer route would invariably be costlier. The following points also merit consideration.

The Barren Rock phosphate project is simple and of small dimensions. It seems, however, that no substantial progress was achieved in the last two years in going ahead with its implementation. The Research Centre has yet to issue its findings on the agronomic aspects of the project which are essential to its success. The BDPI is confident that the project feasibility report will be available in three to four months. This looks unrealistic in view of the stage of work with the Service Géologique and the Research Centre. Even chemical analysis of rock remains to be done, although evaluation of the deposit is reported to have begun sometime in 1976. In the meantime project costs have gone up. There is an immediate need to prepare a programme with a specific timetable, bringing about the required degree of co-ordination between the various agencies concerned and preparing a project report as a basis for investment decisions. The mission feels that all this should not take more than six months.

The Service Géologique is very much interested in the investigation of the Majunga nodules of the Majunga basin but lacks both experience and equipment. An experienced geologist is immediately needed. Even for the island deposits it would be useful to have an expert who could supervise and guide prospecting, have the requisite data compiled, and prepare the ground for formulation of the project report. A project of this magnitude would not and should not take much time. The services of a mines manager would thereafter be required to run the project for a brief period, say one year in which time the local talent could be adequately trained to take command and carry out operations without any outside help.

C. Mauritania

Although a number of locations with potential phosphorite horizones have been identified in Mauritania, so far no deposit of commercial significance has been discovered. The regional dispersal pattern of phosphates in the western Sahara makes it highly likely that significant rock phosphate deposits exist in Mauritania. However, the Government will have to accord sufficiently high priority in its scheme of things to the exploration programme only after which a clearer picture will emerge. Given the results, rock phosphate could, over a period of time, become one of the major items of export from Mauritania. The plan of action outlined below is suggested.

Intensive drilling will have to be done in Mauritania to determine the size and grade of rock phosphate deposits and reserves. The size of the ferrophosphorous reserves of the Oued Chig zone is not known. In the absence of tests it is not known if the iron constituents can be tapped out of the phosphatic fraction by thermal treatment with suitable additives. Laboratory tests should be carried out on samples from this area.

The information available about the ore reserves and the grade of the phosphate beds of the Cive region do not permit any inference about the potential of the deposit.

The high proportion of associated carbonate in the Boghe phosphate horizon implies a high percentage of loss on ignition. If sizeable ore reserves are found, the thermal process of beneficiation may be necessary. A systematic exploration programme using close-spaced drilling is urgently needed to determine the size and grade of the reserves.

D. Peru

Phosphorites in siliceous diatomaceous oozes have been found on south-west African and Peru-Chile shelves and represent the youngest phosphorites found to date in the oceans (Holocene-Late Pleistocene), and this type of deposit usually contains huge phosphatic reserves.

With a proven reserve of about 500 million tons and an estimated reserve of 10 billion tons, the Seohura deposit not only promises to make Peru self-

sufficient in phosphatic fertilizers, but could also become the major supplier of phosphates to the Andean countries and possibly to countries in Asia. There is no doubt that the deposit would change the Economy of Peru once the systemetic programme of exploration, mining, beneficiation and utilization of phosphates is completed. For various reasons the rock phosphate project could not be implemented in the past. Implementation of the present ambitious project according to schedule is essential. The satisfactory exploitation of the deposit will require a well-co-ordinated programme. For the expeditious development of the project the following points are suggested for consideration.

The rock phosphate deposits of Peru are extensive and provide an excellent base for a regional project, particularly in the Andean group of countries. It is reported that Bolivia's copper smelting capacity could be further expanded if an outlet could be found for the by-product sulphuric acid. The rock phosphate of Peru offers scope for its utilization.

The situation with regard to the export of fertilizers or concentrates from Peru looks very uncertain. Rock phosphate could possibly find a ready market in the neighbouring countries, and also possibly in Asia. This, however, requires a market survey of the domestic as well as the external market. It would be disasterous if the concentrates/fertilizers failed to find a market. The problem assumes greater seriousness when viewed in the context of the very small domestic demand. The present demand pattern of fertilizers is both erratic and low. Immediate steps will have to be taken to promote the use of balanced fertilizers. A survey is called for in this area. An in-depth study to identify the factors inhibiting increased use of fertilizers along with remedial measures is badly needed.

Since a joint venture with the Empresa Nacional Adara de Investigaciones Minerales, S.A. (ENADIMSA) (Adaro National Mineral Research Company) is envisaged, it is expected that adequate training of local talent will be provided. Particular attention will have to be paid to the training of semi-skilled and skilled staff for the phosphate mines and beneficiation plant.

Direct application of rock phosphate is not being pursued, for lack of funds, despite encouraging results reported by research institutions. Agronomical research needs to be reviewed, if possible, with the help of an outside expert. Since the sea will be the source of the water supply for

industrial and other purposes, water treatment will be a very critical area in project formulation. It is considered necessary urgently to obtain the servioes of an expert. The type of fertilizers proposed to be manufactured at Bayovar need closer scrutiny. This is yet another area requiring the services of an expert.

Exploration in the Sechura region should be intensified so as to cover the area as quickly as possible. The Bayovar project will have to be implemented in the stipulated time. Any delay would affect its viability. In fact, it would be advisable to have a quick reappraisal of the rock phosphate projeot, the feasibility of which was studied some time ago. Sinoe the proposal is to integrate it with the fertilizer complex, any esoalation in its cost estimates will affect the economios of the Bayovar projeot.

E. Saudi Arabia

Despite the existenoe of two sizeable phosphate deposits, no work seems to be in progress on rock phosphates in Saudi Arabia. The very high ore to overburden ratio of the phosphate horizons, which makes underground mining almost a necessity, the loss of P_2O_5 oontent, the difficult beneficiation of the ore, transport bottlenecks and the uncertain water supply make their eventual exploitation a difficult undertaking. These considerations, together with the fact that phosphate is a low-prioed mineral and that it is easily available from neighbouring countries possibly acoounts for the low priority given to rock-phosphate exploration as compared with non-ferrous/noble metals. The deposits, however, are of sufficient interest to justify a plan of action along the following lines.

Of the two currently-known phosphate deposits of oommeroial significance in Saudi Arabia, the upper zone of the Turayf area is suitable for early development. The results of oonoentrating the oaloareous ores of this area by Cerphos (France) need to be followed up and subjeoted to pilot plant tests. The availability of cheap fuel sources in Saudi Arabia will make it easier to adopt the oaloination prooess of benefioiation. A thorough exploration of the oaloareous phosphatic ore in the Turayf region will have to be undertaken to make a more realistic estimate of the size and grade of the reserves. This would require oommissioning an expert agenoy.

The services of reputable ore-dressing laboratories would be required to undertake investigations with a view to upgrading argillaceous ores of the West Thaniyat deposit through the removal of clayey fractions. In other words, studies on beneficiation processes would be necessary.

Preliminary studies will have to be carried out to establish approximate production costs. No such data was made available to the mission. Hence it is not possible to say whether such studies have been done. While drilling programmes will have to be intensified, further field work in nearby areas would also be useful. For instance, lower-grade phosphate rock (with a different mineralogy) near Tarayf should be considered in connection with any more thorough study of phosphate resources. It would also be necessary to undertake a preliminary assessment of water availability in the Thaniyat-Turayf area. A study of infrastructure in the deposit areas will provide preliminary data for working out production costs.

F. Sri Lanka

The discovery of the Eppawala carbonate complex and its subsequent exploration is a considerable achievement of the Geological Survey Department of Sri Lanka and has revealed the country's potential with regard to commercially-exploitable phosphate deposits. The deposit could make Sri Lanka self-sufficient in rock phosphates. Every effort should therefore be made to ensure the early development of the phosphate reserves of the Eppawala carbonate complex. The most urgent need is to undertake immediately the various beneficiation tests to remove undesirable ingredients of the ore. The following plan of action is suggested.

The low percentage of core recovery should be cross-checked. Dry drilling (only for the apatite zone) could be used in a few places adjacent to a bore hole in which wet drilling was earlier carried out and the efficiency of recovery poor. The results obtained through the two types of drilling can then be checked and the accuracy of the results established. For determining the true thickness of the leached apatite-bearing zones, bore holes should be drilled on the highest areas of the carbonatite massifs. The nature of compositional variation, both laterally and vertically, should be determined by close-spaced drilling of 200 ft and analysis of the core samples carried out at a vertical interval of 2 ft. The occurrence of giant-sized apatite crystals measuring

more than one foot in the Eppawala carbonite complex needs careful examination. The mineral assemblages of the carbonatite complex strongly suggests a phase of carbonate mineralization. On the other hand, seldom does a carbonatite massif develop giant crystals, which form only in a condition of slow cooling at a low temperature range with very low viscosity of the melt. As the problem is very interesting from an academic point of view, co-operation with a university department seems desirable.

The overburden to ore ratio is insignificant. This fact, coupled with the relatively loose nature of the overburden and the ore-bearing horizons, facilitates mining. The consumption of explosives will also be low. A gradual mechanization of the mines will bring dividends, with a reduction in dependence on foreign sources and the training of the existing staff to take up skilled mining jobs which will improve both their output and their wages. The high percentage of P_2O_5 coupled with the large amount of substituted chlorine will make the rock unsuitable for either wet process phosphoric acid or the manufacture of triple superphosphate. The ore will, therefore, require prior beneficiation for the removal of the undesirable constituents. Defluorination involves calcination at a high temperature and a substantial amount of thermal energy. The production of phosphoric acid by the basic phosphorous process deserves consideration.

The scope of direct application in acidic soils need further study. Agronomic studies (pot culture) may be conducted with apatite samples from Eppawala to observe their effectiveness in direct application with different types of soils and crops. It would de desirable to grind phosphate constituents to varied degrees of fineness in these studies.

G. United Republic of Tanzania

The only deposit worth commercial exploitation in Tanzania is the fossil guano-type deposits of the Minjingu-Kopji region. The total proven reserves are of the order of 4.38 million tons. The reserves, although not large, do hold the promise of meeting the country's entire phosphatic fertilizer requirement over the next 12 years or so. A considerable amount of work has been carried out by the various expert agencies with regard to geology and ore-dressing. A more realistic assessment should be made of the rock phosphate requirements

of the Tanga fertilizer plant on the basis of which a project report should be prepared and the investment decision taken. Simultaneously, a comprehensive exploration programme based on the modern concepts of phosphate research should be prepared and carried out to discover new phosphorite deposits.

The Tanga plant has so far not attained more than 60% of the installed capacity. STAMICO will have to explore alternative markets if the Tanga plant, for whatever reason, does not consume 120,000 of concentrates, which is the capacity being planned for the rock phosphate project. Export of concentrates will be a difficult proposition, particularly in the present-day situation. The marketing wing of TFC puts the annual requirement of Jordan rock phosphate at 80,000 tons only. These factors have a vital bearing on the capacity of the Minjungu project and its economics. Use of hard ore for direct application to soil would similarly require, among other things, farmer education and extension courses in addition to large-scale field trials and demonstrations before anything could be said about its use. It must be stressed that these two areas should be re-examined before the capacity of the beneficiation plant is decided upon. The feasibility of direct application of hard ore requires further investigation. Expeditious action will have to be taken in this direction. If not utilized, the hard ore will be discarded, thus adding to the cost of the project. For agronomic research, the services of an outside expert are recommended.

The life expectancy of the mines, as projected by STAMICO, is rather short. Unless the beneficiated rock from Minjungu is used in the Tanga plant, it is difficult to say what will happen. A sufficient quantity of rock will have to be used in the fertilizer plant before the investment decision on the beneficiation plant is taken. Blending with Jordan or another imported rock may have to be done in case exclusive use of beneficiated Minjungu rock affects plant efficiency. It would be necessary to provide the services of mining and ore-dressing engineers in the initial stages of the project. The experts could also train local talent.

The services of a geologist will be required for drawing up a plan of exploration of promising areas and making a quick survey to discover any remaining phosphate deposits.

III. STATUS OF ROCK PHOSPHATE DEPOSITS AND THE PHOSPHATIC FERTILIZER INDUSTRY

A. Chile

In Chile preliminary studies of rock phosphate deposits are being conducted by the Instituto de Investigaciones Geológicas (IIG) of Chile, which is a Government agency. The most promising deposit is that in Mejillones, on which work is continuing. The deposit is located at an altitude of 2,000 m in the deserts of northern Chile at 21° 14' S and 70° 25' W. The nearest city is Antofagasta, 45 km south of the deposit. Antofagasta is close to the Chuquicamata, Exótica and Mantos Blancos copper mines and is a seaport. The city of Mejillones is located 20 km north of the deposit and is also a seaport. It is reported that facilities for handling rock phosphate and fertilizers exist at Mejillones. Paved roads connect the deposit with the cities of Antofagasta and Mejillones, and a railroad crosses over the deposit.

The basin where phosphate rock is found covers an area of 10 x 12 km and the deposit goes down to a depth of 60 m. The prospect is in the early stages of exploration. The possible reserves are estimated at more than 27,000,000 tons averaging 7% P_2O_5 Of this figure only a little over 2 million tons have been proved since proving began in March 1976. The ore bed is horizontal with an average width of 1.5 m. The rock is soft with little overburden.

Analysis of the phosphate rock gives the following composition:[1/]

SiO_2	5.04
Al_2O_3	5.63
FeO	1.68
MgO	1.69
CaO	20.68
Na_2O	10.57
S	0.63
I_2	0.12
P_2O_5	11.66

The above analysis cannot, perhaps, be called a representative sample.

1/ Source: IIG .

Large-scale samples will have to be analysed before any definite opinion can be expressed about the chemical composition of Mejillones rock phosphate. In fact, prospecting is in its very early stages and must be intensified.

Preliminary studies of sedimentary rocks carried out by IIG in 1972 cover the Tongoy Basin; Quiciquina Island in Upper Cretacic rocks; Quebradas Melendez, Carrillos and Chanareillo in Lower Cretacic rocks; and Quebrada Asientos in the Lower Jurassic Rocks.[2/] The Tongoy deposit is located at 30° 25' S and 71° 34' W at an altitude of 180 m above sea level in the arid zone. The nearest cities are Coquimbo and Serena. A road of about 30 km reportedly connects this area with the Pan American highway from which point Coquimbo is about 50 kms and La Serena about 60 km. The distance to Santiago, the main industrial city of Northern Chile, is about 350 km. Coquimbo is on the sea. At present, no railroad exists from the deposit to this seaport. The deposit extends over an area of 30 km^2. Phosphate rock is found 80 m to 100 m below white sandstones with an average stratum thickness of 0.6 m. Estimated reserves range between 2,700,000 tons to 3,240,000 tons of tricalcic phosphate. The P_2O_5 content is reported to be higher that the average P_2O_5 content of the Mejillones deposit. No data, however, was made available to substantiate this claim.

Very little is known about the remaining three areas. According to the IIG, the Quiriquina area has phosphates averaging 2% to 5% P_2O_5. In the Upper Cretaceous rocks, layers of phosphate limestones, associated with black chert and shales, are reported to exist with from 5% to 6% P_2O_5 content and thickness of about 100 m. Layers of calcareous shales of 0.5 m to 1.0 m thickness with less than 5% P_2O_5 are reported to exist in the Jurassic rocks.[3/] This black shale-chert association is characteristic of many phosphogenic provinces. In view of occurrences of P_2O_5, though in lower concentration, the interlayered sequences of the Quiriquma area require thorough geochemical prospecting. All these regions require intensive exploration and prospecting before any further work could be suggested. No data regarding forecasts of fertilizer consumption in Chile is available. Rock phosphate was imported, mainly from Florida (United States), Morocco and Senegal until 1974, when there was a switch-over to the import of finished fertilizers, which is still continuing.

2/ Report of P. de Angello, 1972, IIG, Apartado No.72.

3/ Source: IIG.

The following quantities of rock phosphate were imported between 1969 and 1974.[4/]

Year	Tons
1969	23,500
1970	75,400
1971	37,000
1972	50,000
1973	75,000
1974	80,000

Some quantities of rock phosphate imported earlier are reported to be still lying unconsumed. The TSP plant is reportedly producing only single superphosphate and TSP is being more cheaply imported.

With regard to phosphatic fertilizers, consumption has been as follows[5/]:-

Table 1. Phosphate Fertilizer Consumption[a/]

Year	Fertilizer sales	TSP (P_2O_5)	SSP (P_2O_5)	DAP (P_2O_5)
1971	103,642	72,901	4,718	9,598
1972	84,659	47,370	4,861	5,097
1973	121,151	44,086	7,153	46,647
1974	103,479	57,008	5,231	28,416
1975	57,544	29,412	5,800	10,204
1976	70,848	40,881	3,755	15,206
1977	84,660 (estimate)	46,000	6,250	23,000

a/ Figures given in tons.

The difference between the total consumption figures and those derived from the consumption of TSP/SSP/DAP is made up by guano supplied by the Sociedad Chilena de Fertilizantes (SOCHIF) (Chilean Fertilizer Company.) According to the Sociedad Química y Minera de Chile, S.A. (SOQUIMICH), (Chilean Chemical and Mining Company), the erratic demand for fertilizers in the past few years is attributable to falling prices of agricultural produce, which makes it difficult to make and demand projection. It was not possible to obtain any appointment with the Ministry of Agriculture.

4/ Source: Compañía Sudamericana de Fosfatos.

5/ Source: COSAF.

In these circumstances it is difficult to imagine how the indigenous rock phosphate could be utilized by the domestic fertilizer industry. The problem is further complicated by the fact that the deposits have not been fully explored, and in the absence of complete data, their viability cannot be determined. For obvious reasons phosphate rock presently receives low priority in the scheme of things in Chile.

B. Madagascar

Although no large deposits of rock phosphate exist in Madagascar, the occurrence of several types of natural phosphates has been noted, some of which are of economic interest particularly when viewed in the context of the P_2O_5 requirements of the country. According to BDPI, Madagascar would need 8,500 to 11,400 tons of P_2O_5 by 1980.6/ The island deposits discussed in this report provide a good source of phosphates to meet the country's requirements over the next few years.

Apatite is found in the southern regions of the mainland in Bekily, Ampandrandava and Keraketa in association with mica and pegmatites. The P_2O_5 content of the deposits is, however, low (2.6 - 7.9%), and the known quantity is too small to be exploited. The low P_2O_5 values also rule out their direct utilization in agriculture. The phosphate modules of the Manjunga basin are of marine sedimentary origin. The known reserves are, however, small and have P_2O_5 values around 15%. The modules, in their present stage, do not hold out any economic interest. Scattered modules are found in the regions of Ambato, Boeni, Anjiajia, Maevarano, Marovoay, Soalala and Narind. The guano deposits in the region of Tulcar contain 4% nitrogen, 15% P_2O_5 and 1% K_2O. The reserves have been estimated at about 10,000 tons only (i.e. 1,500 tons of P_2O_5). Because of the smallness of the reserves and the difficult access, the deposit could at best be of limited regional interest only. Cattle provide another source of P, namely bone phosphate. In fact, this is the only type manufactured locally.

A large number of islands situated in the Mozambique channel possess strata of phosphates of guano origin. These are of a particular economic importance to Madagascar. The island of Juan de Nova, located 135 km west of Madagascar, was investigated and regularly exploited between 1952 and

6/ Source: BDPI.

1968 by the Société Française des Isles de Madagascar (SOFIM). In 1968 Juan de Nova was sold to the Mediterranean club. The total reserves there are estimated to be of the order of 4 million tons. Exploitation was done manually and humidity reduced from 16% to between 8% and 10% by sun-drying. The richer-grade material (30% P_2O_5) was exported to South Africa for the manufacture of phosphoric acid and the lower-grade (20% P_2O_5) to Mauritius for direct application in sugar-cane plantations.

Phosphates, similar to those of Juan de Nova, are found in islands situated from 50 km to 100 km to the west and north-east of Madagascar. Unfortunately, no exhaustive inventory of reserves has so far been made for these deposits. The service geologique is currently carrying out investigation in these islands, the most notable among them being the group of Barren islands, which are reported to contain about 400,000 tons of phosphates considered enough to meet the P_2O_5 requirement of Madagascar in the next ten years at the rate of 20,000 t/y of 25% grade.

It appears that there are between 0.5 to 1.00 million tons of phosphorite[7] in these islands which are restricted in strata like the deposits at Juan de Nova. The deposits are in the form of pockets which, in turn, are either in the form of a circular trough (1 to 3m in diameter) or in the form of a long trough (up to 10 m). They are composed of a superficial bed of greyish powder of an average thickness of 0.5m and containing 15 to 20% P_2O_5 in the form of tri-calcium phosphate, and of a harder bed, sometimes rock-like, of red-maroon colour. The Service Geologique is currently analysing the samples. The richer-grade Juan de Nova rock analysis is given below:[8]

Constituent	Percentage
BPL	66-70
$CaCO_3$	0.3
CaO	8.5
Al_2O_3	0.24
H_2O	8
LOI 110°C	4.0
Organics	1.3

7/ Source: Service géologique.

8/ BDPI Project de production d'engrais au Madagascar, Vol.II (source: SOFIM).

The four islands in the Barren group are Maroantly, Nosy Andotra, Nosy Andrano and Nosy Lava. Phosphate occurences have also been reported in other islands: Mangiho (40 km north-west of Ambilobe, 2,000 tons of phosphate powder, 15% P_2O_5), Isles glorieuses (north-west of Madagascar, 150 ft long and 60 ft wide, ore body from 3" to 5" thick), Ile de Lys, Mananjeba, etc. (very little known about these). The exploitation of the Barren island deposits does not appear to pose any serious problems. This was studied by F.J.E. Van Dierendonek in his report of March 1975. On the basis of SOFIM's experience it was suggested that manual exploitation of the deposits was economically viable with the transport of ore by tractor trailer. The ROM would have to be classified so as to get a grade of 25% P_2O_5. Since phospheric is in tricalcium form and needed for rice cultivation, three-stage processing was recommended: ensuring a uniform grade of P_2O_5; screening to make it 25%; and reducing the moisture content to 4%. Ball-mill grinding and drying facilities in a closed circuit were to complete the job. It was further recommended that processing facilities will have to be installed on the west coast of the mainland where port facilities exist, so that the finished product could be transported to the consuming centres in the interior. The ROM could be bulk transported in 400 to 600-tonner ships to the processing plant. Plastic bags could tolerate higher moisture content but paper bags were recommended for packing, as they are cheaper. It was calculated that the total cost of the project would come to $242,000, excluding working capital and licence fee for exploitation. The maximum sale price worked out was 20,000 Malagasy franc (FMG)/ton, as against the 1974 imported price of FMG 55,000/ton ex Tamatave. Handling expenses pushed up the price to FMG 75,000/ton. The Government was subsiding the sale of imported fertilizer by 50%. Production of island phosphates and their direct use as fertilizers was therefore much cheaper. So far no action has been taken to implement the project.

As indicated earlier, the Government wants to proceed with the implementation of the project. The Service Géologique and the Centre de Recherches Agronomique at de Développement Rural are working on the feasibility of the scheme, which is reported to have been approved in principle by Government. The exercise is expected to be over by the end of the current year when the investment decision will be taken by the Ministry of Rural Development. The BDPI is co-ordinating the activities of the agencies concerned. It has been tentatively decided to locate the processing plant at Majunga. The project is expected

to be completed within six months of the starting date.

C. Mauritania

Phosphates in Mauritania are found in two different geological settings in the different formations of the Taoudenni basin (West African platform) and in the Eocene sediments of the Senegalo - Mauritanian basins. Work is currently concentrated mainly on the Eocene sediments, but so far no commercially exploitable reserves have been proved.

The phosphates of the Taoudenni region are situated in two areas, east of Atar and south of Chinguetti. Mineralization is concentrated north of the line Atar-Chinguetti, around the point with co-ordinates 13°W, 20° 40'N and along a profile S.W. of the point 12°W 20°N. The first area is accessible by road. The climate in the above region is desert-like, with maximum temperatures of 30°C and a minimum of 15°C in the winter months (November-March). In the summer months (June-September) maximum temperatures go up to 41°C and the minimum goes down to 26°C. Rainfall occurs mainly in August and September, averaging 100 mm. Heavy rains have been recorded in the past when as much as 71 mm rainfall was recorded in a single day.

The phosphates in the northern part are accessible by the Atar-Chinguetti road, those of the southern part along the Oueds. The population of the region is concentrated in Atar. Only minor occurrences of phosphates have been observed in the lower Cambrian metasediments belonging to the Atar group. Occurrence of traces of phosphates have been confirmed by Ammonium molibdate tests in 1.5 m thick quartzitic sandstones. Similarly, traces of phosphates have been found in a 2.00 m thick quartsitic sandstone in Oued Agbodana. The sandstone sequences of Nouatil, Bathat Ergil, Jbeliat and Bathat Ntichedid belonging to Cambrian and Ordovician series are also considered likely phosphogenic provinces. These areas extend to over 80 km. No assessment of this possibility can be made until detailed studies are conducted. The difficult access and the severe desert conditions, however, will pose serious problems in any such studies. Along the southern border of Adrar, a linear zone extending over 100 km from Ouad Chig to the zone of Mauritanides, there are 5 cm to 30 cm thick beds of ferrophosphatic pebbles, quartz and iron oxide and hydroxide minerals. Oolitic phosphates with conspicuous concentric structure and measuring 200 microns in size have also been observed. Extremely

fine-grained brownish phosphates also occur as cementing material between the quartz grains. Analysis of five samples from the richest levels gives the following mean composition 9/:

	Percentage
P_2O_5	19
Fe_2O_3	22
Al_2O_3	6
SiO_2	39
CaO	1-2

These phosphates perhaps are the result of double transformation of calcium phosphates into aluminium phosphates, and after that into iron phosphates.

The other important occurrences are those restricted along the border of the Sengal river and extending from Cive to Boghe. Two deposits have been recognised, the Cive deposit (150,000 tons) and that in the region of Boghe - Kaedi - Aleg, where the consortium of Mauritanian phosphates undertook exploration work in 1974 and 1975 and intends to continue the same with the drilling programme. The deposits are fringed on the N.E. by yellow formations belonging to the Eocene series and on the S.W. by the recent alluvium.

The maximum and minimum temperatures from December to February are 31°-35°C and 13°-16°C respectively. During the period April-October the maximum temperature ranges between 35°-43°C and the minimum between 22°-26°C. Rainfall is around 675 mm and occurs mainly from June to October. The roads Nouakchott-Boutilimit-Aleg-Kaedi-Meghama and Nouakchott-Rosso-Boghe-Kaedi are reported to be in good condition with large tarmac sections, but parts of the roads are in bad shape during the rainy season. Kaedi is connected with Nouakchott by air and the river also connects it with the port.

In the Cive deposit, the phosphatic materials are concentrated in four interlayered beds. The P_2O_5 content ranges between 25% and 27%, but the reserve is meagre. No further prospecting is being contemplated in this area. The other phosphate deposit lying in the Kaedi-Boghe-Aleg area is restricted to Lutetian formations. The associate minerals include limestone, dolomites and

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9/ Source: SNIM

clays. The deposit has been prospected by a consortium of SNIM, Bureau de Recherches Géologique et Minerie (BRGM), Geomin (Romania) and Société Sénégalaise des Phosphates de Thiès. Drilling operations carried out during 1974 and 1975 helped only in defining the zones of interest.10/

No estimates of probable reserves have been previously made. The phosphate-bearing bed has a thickness ranging from 2.10 m to 5.30 m, and the grade varies from 11.6% to 20% P_2O_5. A part of the sector with seven bore holes spaced at 5 km intervals has an area of about 100 km^2. Prospecting work was stopped in 1976 as some of the consortium members were reluctant to undertake any further prospecting. Inadequate drilling capacity available for the prospecting of rock phosphate has also hindered the expeditious implementation of the programme. Most of the available drilling rigs have been deployed in the country's copper exploration programme. It is, however, understood that it would be possible for SNIM to spare some drilling rigs from copper prospecting. This would ceratinly improve the tempo of phosphate exploration, but work can be done only for another three months in the current year. As the availability of the drilling rigs depended on the timely completion of the copper exploration programme, no definite plans for phosphate exploration have been made.

Analysis of cive rock phosphate gives the following chemical composition11/:

	Range (%)
P_2O_5	25-27
CaO	29-35
SiO_2	17-19
Al_2O_3	7-10
Fe_2O_3	4-7
Other chemicals (not analysed)	6-8

10/ Ibid.

11/ Ibid.

Some of the samples analysed from the Kaedi-Boghe-Aleg area show the following composition[12]:

	Range (%)
P_2O_5	11-20
Fe_2O_3	0.5-1.7
SiO_2	3.62
CaO	27.16-38.24
Al_2O_3	0.96-3.00
LOI 1000°C	6.90-33.84

D. Peru

The biggest deposit of the country, the Bayovar rock phosphate deposits, are located in the Sechura desert of Peru between 5° 09' - 6° 15' S and 80°30' - 81°05' W. The climate is typical of deserts with very little rain. The maximum temperature goes up to 32.7°C and the minimum goes down to 14.1°C with a maximum moisture of 94% and minimum of 20%. The altitude of the deposit is about 30 m above sea level. The deposit is located in the Sechura district, Piura province, and is about 120 km and 60 km from the cities of Piura and Sechura respectively. Piura is about 1,030 km north of Lima and 300 km from Ecuador. The deposit is accessible both by land and air. An asphalted road of 60 km in length exists between Piura and Sechura, but the road between Sechura and the mines is a paved one. There is an airport which permits the landing of small aircraft. About 30 km from the deposit is the port of the Petro Peru Project, which is fully equipped to handle the loading and unloading of oil. The port is, however, for the exclusive use of Petro Peru. There is a proposal to develop handling facilities for rock phosphate at a distance of about 3 km from the Petro Peru port. The town of Piura has a population of 700,000. The principal activity in this area is agriculture and fishing. People are generally educated up to primary level. Semi-skilled and skilled personnel for the mining/benefication project will have to be brought from outside the region until local talent is adequately trained.

12/ Ibid.

The Sechura phosphate deposit extends over an area of 200 km x 680 km covered quaternary silts. The marine sedimentary rocks that form the basin are of the tertiary age. Probable reserves are estimated at 10 billion tons, of which a little over 500 million tons have been proved. Further proving is continuing. INGEOMIN has a well-defined programme for it. In the explored areas no structural freaks of any regional influence have been noticed. The deposit is formed by seven phosphorite beds with its interbeds, establishing a formation almost uniform throughout its extent. The P_2O_5 content of the beds and interbeds, just as the structural characteristics and the mineralization, presents only small variations. The phospheric beds are of uniform thickness, the less potent varying from 0.30 m to 0.40 m, and the more potent from 1.20 m to 2.00 m. The average P_2O_5 content is around 15%. The interbeds have thicknesses of from 3 m to 7 m, with 3.5% to 7% P_2O_5 having diatomite as an impurity.

In all, nine areas were explored, two of which two areas were defined as area I and area II. Since area II is richer and more promising, Minero Peru have decided to begin mining in this region. The main consideration has been that the ore/overburden ratio in this zone is more favourable, and this will reduce the cost of mining in the initial few years of operation. For this reason the areas to be mined in the first few years have been more thoroughly drilled, sampled and analysed than the other areas. Detailed analysis has been made of the Bayovar rock phosphate. The chemical composition of the rock is given below[13]:

	Range(%)
P_2O_5	16.64 (average)
K	0.23 - 0.31
Ca	37 - 42
Mg	1.00 - 5.20
S	2.40 - 3.44
Na	2.99 - 5.52
Cl	2.63 - 5.43
Si	19.50 - 20.75
Al	0.11 - 1.36
Fe	0.40 - 0.71
F	5.00 - 6.80

13/ Source: Minero Peru.

Mn	0.003 - 0.009
Cr	0.00 - 0.0184
B	0.002 - 0.0010
Cu	0.0400 - 0.0660
Zn	0.47 - 0.67
Ba	0.35 - 0.68

Pilot plant tests have been completed. The beneficiated rock will have the following composition.[14]

	Percentage
P_2O_5	30.50
CaO	47.80
K_2O	0.10
SiO_2	3.25
Al_2O_3	0.85
Fe_2O_3	0.63
F	2.91
CO_2	3.25
Na_2O	1.74
MgO	0.76
Cl_2	0.06
LOI 850°C	9.31
Organics and others	3.20

Phosphate area II of the Bayovar project is located in the wetern part of the grand depression of the Sechura deposit. Its gravity centre is about 45 km south-east of the project location. According to geological characteristics, there are two well-defined zones - the outcrop zone and the non-eroded zone. The outcrop zone presents an elongated shape in a south-east/north-west direction covering an area of 10 km x 2 km. It represents 38% of the total explored surface in area II. The part that presents better geological conditions and facilities

14/ Ibid

for mining is located in the central zone and in its elongation to the south-east which has been intensively investigated recently. The characteristics listed below have been noted[15]:

Soft fold of south-east to north-east with 1.4% maximum gradient in sides.

Soft pitch and almost uniform beds south-east to north-east with 2.3% gradient in zones of greater slopes.

Uniform texture of clay-tufaceous diatomites with average 30% H_2O content.

Thin fissures and fractures of small tension displacement to 0.3 m, with crystallized gypsum veins which constitute ways of water filtration.

Reserves have been calculated by the general influence area method, i.e. general area of the explored surface x average thickness x specific gravity. Reserves for the blocks were defined by the influence in grades of each drilling and for each phosphate bed.

It is evident that Minero Peru has done exhaustive work on the Sechura deposit area II. In fact, the project report on mining in this area has been completed. Work, however, could not begin for lack of funds. As stated above, pilot plant tests have confirmed that the Sechura rock can be upgraded to produce a dry concentrate of 30.5% P_2O_5. The mining/beneficiation project envisages a production of 880,000 tons per year (t/y) of concentrates in the first phase. In the second phase a production of 2,000,000 t/y is being contemplated, but this is still in the planning stage; even pre-feasibility studies have yet to be prepared. Minero Peru plans to use scrappers in mining in the first three years. Excavators are to be deployed from the fourth to the twentieth year of the project. Other ancillary equipment includes bulldozers, tractors, water sprinklers, pumps, lubricating vans, trucks and power generators. The cost of mining (with scrappers) is estimated at $5.24/ton, and $2.4/ton when bucket wheel excavators are put in operation. At full capacity the end product is expected to cost $12.32/ton. For producing 880,000 t/y of concentrates, around 6 million tons of rock will have to be annually handled.[16] At a price of $27/ton of concentrates the ROI is calculated at 7%. This will go up to 11.4% if the price is taken at $30/ton.

15/ Ibid

16/ Ibid

Minero Peru is at present negotiating a joint venture with ENADIMSA, a subsidiary of Spain's National Institute of Industry, for setting up a fertilizer complex using the phosphate deposits as captive mines. The mining/beneficiation project will have the same capacity (880,000 t/y of concentrates) which will be used to produce 450,000 t/y of TSP and 85,000 t/y of DAP essentially to cater to the export market. The sulphuric acid plant to be set up at Ilo will have a capacity of 600,000 t/y and will form part of the complex. Requisite quantities of amonia will be supplied by Petro Peru. Sulphuric acid from Ilo and rock phosphate will yield 200,000 t/y of phospheric acid of 54% P_2O_5. ENADIMSA is preparing the feasibility study for the fertilizer complex which is expected to be ready by the end of 1977, after which the investment decision will be taken.

Although Minero Peru has negotiated the joint venture with ENADIMSA, it has yet to receive Government approval. It appears, however, the the Government has agreed in principle to the proposal. ENADIMSA is expected to participate in the equity and will be responsible for all pre-investment expenses and the foreign exchange component of the project. After the project is approved a new company (Empresa Minera Especial) will be floated with ENADIMSA and Minero Peru as partners.[17/]

According to preliminary estimates the rock phosphate project is likely to cost $92,958,000. The fertilizer plant cost estimates are put at $114,290,000, and those of the sulphuric acid plant at $56,243,000, making at total of $263,700,000. To this would be added the refinancing cost of $9,381,000. The total cost of the project is, therefore, estimated at $273,081,000. Of this sum $93,161,000 will be in foreign exchange and the balance of $170,539,000 + $9,381,000 in local currency. On present indications, the expected date of project completion will be 1 January 1981.[18/] The local currency cost will be provided by Minero Peru and Corporación Financiera de Desarrollo (COFIDE), the state financing corporation. In Peru, planning, programming and evaluation of all public investment is routed through the Instituto Nacional de Planificación. (National Planning Institute). The project cost, even though tentative, appears to be on the lower side.

17/ Ibid.

18/ Ibid.

This is likely to go up further if the time schedule of the project is upset. In view of the present status of the project, the completion date of 1 January 1981 appears to be optimistic. Infrastructure facilities will cost both money and time, particularly water for processing and installation or port facilities. Complete implementation of the project is estimated to take five years, the first two years for the rock phosphate and the next three years for the sulphuric acid and the fertilizer plant. Production of rock phosphate is expected to begin in the third year and that of fertilizer in the sixth year. The life of the project is estimated at 20 years. As stated above, the start of the integrated project is expected to be 1 January 1981. The financial structure of the project is shown in table 2 below.[19/]

Table 2. Project financial structure

Budget item	Expenditure (thousands of $US)		
	National currency	Foreign currency	Total
Purchases and construction	116,969	75,772	192,741
Engineering and administration	16,575	6,572	23,147
Capital for research	22,220	980	23,200
Pre-operation interest	14,775	9,837	24,612
	170,539	93,161	263,700
Refinancing			9,381
			273,081

19/ Ibid.

The breakdown of expenditure on the rock phosphate project is given in table 3.[20/]

Table 3. Expenditure breakdown

Item	Expenditure (thousands of $US)		
	National currency	Foreign currency	Total
Pre-mining	846	1,042	1,891
Mining	340	5,851	6,191
Plant	1,900	8,300	10,200
Sea water	2,912	6,558	9,470
Fresh water	227	100	327
Energy	1,646	1,776	3,423
Workshop and stores	2,796	1,004	3,800
Housing	1,021	-	1,021
Roads	3,059	-	3,509
Port facilities	8,944	1,752	10,696
Engineering and administration	8,645	1,966	10,611
Incidental expenses	3,780	2,540	6,320
Working capital	5,400	980	6,380
Pre-operation interest	1,993	2,127	4,120
Investment	4,857	148	5,000
TOTAL	58,819	34,139	92,958

Field experiments carried out by some research organizations, including the Agricultural University of Lima, have shown encouraging results when the concentrated rock, assaying 30.5% P_2O_5, was applied directly to acid soils of the central and northern highlands of Peru. The quantity applied varied from 150 kg to 400 kg per hectare.[21/] The programme of direct application had to be given up for lack of funds. Minero Peru estimates that about 10 million soles are required for further research in this direction in the next 18 months and another 150 million soles will be needed to make the programme a success.

20/ Ibid.

21/ Ibid.

The high cost of the programme is attributed to difficult access to the areas concerned and staff costs. The country's present development plan makes no provision for this programme.

Demand for phosphatic fertilizers in Peru is low and is unlikely to grow substantially unless vigorous promotion efforts are undertaken. The demand for rock phosphate is therefore poor. The average of rock phosphate imports in the last five years has been around 30,000 tons and may remain pegged around this figure in the next three years. Table 4 gives details of consumption, production and import of DAP, TSP and SSP[22]:

Table 4. Recent phosphate statistics [a]

Year	DAP			TSP			SSP		
	Consumption	Imports	National production	Consumption	Imports	National production	Consumption	Imports	National production
1975	6.2	36.7	-	4.2	12.4	-	7.7	-	6.3
1976	17.1	-	-	7.2	-	-	7.5	-	9.9
1977 (estimates)	19.0	2.5	-	10.0	12.0	-	10.0	-	8.5

[a] Figures given in thousands of tons.

Consumption, in terms of P_2O_5, is expected to reach 14,492 tons, 16,165 tons and 17,941 tons in 1978, 1979 and 1980 repectively on current projections[23]. The SSP plant, of INDUS, is working much below capacity. Consumption of phosphatic fertilizers has not shown any improvement in the past few years. A number of reasons are responsible for this, the more important being the lack of adequate promotion efforts, distribution bottlenecks, the high price of fertilizers, and farmers' preference for nitrogenous fertilizers. Unless immediate steps are taken to increase the use of phosphatic fertilizers in Peru, almost the whole of the proposed fertilizer production will have to be exported.

The Sechura deposit is ready for immediate exploitation by open-cast methods of mining. Unfortunately work could not be commenced earlier for lack of necessary funds. That perhaps is the reason why consideration is being given to a joint venture with ENADIMSA which would meet the financial

22/ Source: ECI.

23/ Ibid.

needs of the project, including the foreign exchange component amounting to over 60% of the project cost. Peru does not manufacture earth-moving equipment, all of which will have to be imported. From discussions with those responsible,it was not clear whether FNADIMSA has guaranteed the marketing of the end-products. The fertilizer export market is difficult and requires greater attention. It is in this context that the idea of producing concentrates only in the first stage deserves serious consideration. Foreign exchange earnings from the sale of rock phosphate could partly meet the expenses of the second phase of the project. This, however, is a decision for the Government of Peru to take.

E. Saudi Arabia

In Saudi Arabia, the occurrence of two prominent phosphorite horizons of economic significance has been noted. These two are located in the Sirhan - Turayf sedimentary basin in the northernmost part of Saudi Arabia between latitudes 29°15'N and 32°00'N and longtitudes 37°00'E and 40°00' E. Initially it was the occurence of phosphate rock float in the Turayf area, lying in the north-eastern part of the above-mentioned basin, that attracted the attention of the geologists. Subsequently, the exploration programme carried out by the Tennessee Valley Authority (TVA) between 1966 and 1969 resulted in the discovery of the potentially lucrative phosphate deposit along the south-western rim of the basin, the Thaniyat area. From the geological point of view the phosphorite horizons of the Thaniyat area occur in the lower part of the Hibr formation and also in the overlying upper cretaceous Aruma formation. Widely seperated from this, in the north-eastern desert plains of the Sirhan - Turayf sedimentary basin, is the Turayf phosphate deposit occurring in three numbered zones and belonging to the Paleocene and Eocene Hibr formation.

Of all the hitherto proved phosphate occurrences in Saudi Arabia, the phosphate zone of the Aruma formation at Thaniyat seems to be the most promising. The best phosphate-bearing beds in this zone are referred to as West Thaniyat. At West Thaniyat the zone contains two beds of phosphate. The upper bed of the zone is too thin to be mined underground alone, but would be valuable if the whole zone is mined. However, the lower bed at the bottom of the zone is thick enough to be mined alone by underground methods (overburden ranges from 20 to 100 m). Of the two phosphorite beds at West Thaniyat, the lower bed stretches out over a distance of 10 km along the east-west trending cliff. Core drillings

have confirmed it to be an almost flat bed extending subsurface northwards with a thickness varying from 1 to 2.50 m, the average thickness being 1.65 m. The deposit contains medium-grade ore with P_2O_5 varying from 20% to 26%, averaging 23% P_2O_5. The phosphate ore is soft and friable, and consists of apatite pellets, quartz sand and clayey material. Total reserves based on preliminary calculation have been placed at 20,000,000 tons of ore (30,000,000 tons of P_2O_5).

In the Turayf area, about 2,000 km^2 have been deliminated as a phosphorite-bearing zone. This is on the basis of surface mapping and drilling in three phosphate-bearing zones. Of these three zones, the upper is the most important, comprising three to five or even more beds, and is at the shallowest depth, averaging about 12 m. The average aggregate thickness and P_2O_5 is 2.5 m and 16%. The total reserve of P_2O_5 concentrate in the upper zone is about 1 billion tons.[24/] Compositionally, rock phosphate in the Turayf area is hard and solid, consisting of apatite pellets firmly connected by calcite and silica. Occasionally, however, friable calcareous phosphate has been found locally.

The chemical composition of the West Thaniyat phosphate ores was determined from the samples collected from both weathered phosphorite out-crop and from an adit driven by the TVA. The objective was to ascertain if the fresh phosphate was as soft and friable as the weathered materials at the outcrop, and also to see whether the two were compositionally similar. The analytical results are given in Table 5 below[25/]:

Table 5: Composition[a/] of ore samples

Constituents	Bed 1		Bed 2	
	Outcrop	Adit	Outcrop	Adit
P_2O_5	30.2	29.2	25.2	23.5
Fe_2O_3	0.9	0.7	1.1	1.2
Al_2O_3	0.7	1.0	1.0	1.3
Acid insoluble	2.4	6.6	25.9	28.4

a/ Figures represent % of sample.

24/ Saudi Arabia Project.

25/ Source: TVA report.

The high percentage of acid insoluble corroborates the presence of a high percentage of quartz in phosphate samples collected from bed No. 2 as against the same collected from bed No. 1. Besides quartz, both the samples contain two types of clays. The phosphate mineral in both beds comprises carbonate apatite consisting of ovular pellets and fossil fragments, including shells, invertebrate cavity fillings, bone fragments and teeth. The composition of apatite is given below.

Chemical composition	Percentage
CaO	55
Na_2O	0.6
MgO	0.2
CO_2	3.1
F	4.4
P_2C_5	38.2

TVA has undertaken comprehensive laboratory tests to beneficiate the adit samples collected from Bed 1 and 2. From the tests they concluded that dry grinding followed by benefication through air would yield a product containing 31.4% P_2O_5 with 81% of recovery. A concentrate of higher-grade phosphate could be produced by flotation, but recovery would be as low as over one half of it is too soft to be floated. However, the samples collected and analysed from the core recovered from drill holes put down at West Thaniyat showed a differential behaviour both in respect of their composition and their response to benefication techniques. Much of the phosphate core contained more clay than the outcrop and adit samples and responded poorly to benefication techniques used on the adit ore samples.

The residual surface samples of phosphate rock randomly collected from the Turayf area are hard and firmly cemented by calcite or silica. The chemical composition of six selected/phosphate samples (three calcareous and three siliceous) is given in table 6 [26]:

26/ Source: TVA Report.

Table 6. Composition[a/] of selected phosphate samples

Type	P_2O_5	CaO	Al_2O_3	Fe_2O_3	SiO_2	Acid insoluble	F
				Calcareous			
Sample 1.	5.0	26.2	.82	1.66	6.98	9.21	.42
Sample 2.	13.6	53.8	.21	.10	.51	.61	1.62
Sample 3.	22.6	53.7	.09	.03	.17	.17	2.82
				Silicious			
Sample 1.	6.9	13.2	.27	.12	69.4	74.6	.72
Sample 2.	14.6	22.4	.22	.12	55.1	56.87	1.55
Sample 3.	20.6	30.0	.07	.06	36.6	45.20	2.34

a/ Figures represent % of sample.

The phosphate mineral in the Turayf samples is carbonate fluorapatite. The calcareous phosphate contains calcite as a major mineral phase, while dolomite is in a few samples. The siliceous phosphate always contains chert-like quartz (cement and ground mass) as a major mineral phase and calcite is a minor constituent. Exploratory beneficiation conducted on the calcareous phosphate revealed that calcination followed by screening and flotation might produce phosphate of commercial grade. The siliceous phosphate responded poorly to both flotation and acidulation techniques.

Laboratory tests carried out by Cerphos, France, proved quite encouraging.[27/] According to the test results, the calcareous phosphate of this region could be successfully upgraded to 37% P_2O_5, with excellent recovery of P_2O_5 and a very good Ca:P_2O_5 ratio. The laboratory calcination tests on the calcareous phosphate rock showed a recovery by weight of 49%, with post-calcination treatment resulting in a 37% P_2O_5 concentrate and 88% recovery of P_2O_5.[27/]

No work seems to be going on at present in the rock phosphate sector. Lead, zinc, gold and silver prospecting receive the highest priority in the exploration programme of the country. The Ministry of Petroleum and Mineral Resources has identified factors which prevent immediate development of the rock phosphate deposits.

27/ Poutheir and Graesart, written communication, 1968.

These are: relatively low grade; difficulties in beneficiation because of the larger amount of clay in the phosphorite deposit at West Thaniyat; underground methods of mining because of heavy overburden (in six drill holes the overburden limestone ranges from 26 to over 100 m in thickness); distance of the deposit from the coast (400 kms); and uncertainty of water supply.[28/]

F. Sri Lanka

The discovery of the Eppawala carbonatite complex in the north-west of Sri Lanka has placed the country on the world map as a source of commercially exploitable phosphate deposits. The almost constant association of apatite with carbonatite complex has prompted geologists to regard the latter as one of the important sources of apatite. Not many known carbonatite complexes, with the exception of the huge carbonatite complexes of the Kola Peninsula in the Union of Soviet Socialist Republics, Jacupiranga in Brazil or Palbowra in S. Africa, have been found with phosphate deposits as large as that of Eppawala.

The Eppawala deposit is located in south-western Anuradhapur in north-west Sri Lanka, at a distance of 120 miles from Colombo. The nearest railway station is Talawa, about 8 miles from the deposit and linked with the national railway grid through the northern broad-gauge railway. The deposit can be approached from the town of Eppawala along a minor road to the eastern fringe of the carbonate complex. A high-tension power transmission line supplies the town of Eppawala with electricity. The area covered by the complex comes within the framework of the Mahaweli Ganga Development Project, Stage II, and was intended for settlement once the project is completed. Fortunately the area has now been earmarked for exploitation. There are no perennial streams or rivers in the area around Eppawala. However, a proposed major irrigation channel will cut across the deposit and a suitable channel reservoir will have to be kept once exploitation work starts. This channel will be the major water supply source. The area is in the dry zone area of Sri Lanka. The average annual rainfall is 50.19 inches. The peak period of rains is during the months of October-January and the showers are mainly during the autumnal convectional cyclonic period. The mean temperature is 81°F and the hottest months are from April to October. The area is mainly under teak. The southern part of the deposit is in cultivated coconut land and is settled. Labour is available in

28/ Economic status of Mineral Deposits of Western Saudi Arabia. Technical Record TR-1974-1, Ministry of Petroleum and Mineral Resources.

the area, especially from the town of Eppawala and the surrounding villages. It is, however, seasonal as most of the settlers are traditional farmers and work their fields during the Yala and Maha seasons. Skilled labour for mining, blasting operations or for factory work will have to be obtained from outside.

The carbonatite masses of Eppawala consist of several low-lying, rounded, oval bodies aligned in a north-south direction. They all outcrop from an otherwise gently undulating topography. From the geological point of view, these carbonatite masses overlay the highly metamorphosed pre-Cambrian basement complex consisting of hornblende gneiss, granite-gneiss and charnockite rock variants. The carbonate bodies consist mostly of crystalline limestone with apatite and magnesite, laterite boulders with apatite, and a leached zone containing apatite xenoliths. The leached zone of carbonite massifs has a spear-shaped body. Out-crops of fresh carbonates consisting of crystalline limestone have been observed only sparodically in a few places in the northern part of the complex, but are well exposed along the southern extension.

The lateritic boulders, consisting of apatite crystals set in a matrix of brownish to whitish concretionary/chalky material, occur as scree. The leached apatite zone is similar to the lateritic boulders described above, and is conspicuously present in the northerly out-crops. The leached zone extends to an average depth of 200 feet from the highest point in the area. The apatite in the leached zone is erratically concentrated and occasionally makes up 70% to 80% of the rock.

The contact between the carbonatite massifs and the basement rock is concealed. Controversies prevail over the genesis of these massifs - whether they are products of magnetic crystallisation or represent mobilized injected masses of carbonate rock under conditions of orogenic stress. Mineralogically, the carbonate massifs of Eppawala are quite interesting. Based on the measurement of cell dimensions, two types of calcium phosphate minerals have been identified: appatite representing an intermediate variety between chlorapatite and flourapatite and francolite. The first type is a typical constituent of the fresh carbonatite while the second type represents the white concretionary material conspicuously present in the leached zone. Besides francolite, goethite, rutile and martite have been identified from the matrix that cements together the well-formed primary apatite crystals.

Chemical analysis of the Eppawala carbonatite (fresh) and leached zones show the range of compositional variations listed below.[29]

	Eppawala (9 analyses)	Leached-ore zone rich in apatite
SiO_2	0.58 - 1.67	0.21 - 0.97
TiO_2	Trace	0.14 - 1.20
Al_2O_3	0.01 - 0.04	1.10 - 2.56
Fe_2O_3	0.53 - 1.71	2.27 - 6.15
FeO	-	0.09 - 1.77
MgO	3.93 - 8.29	0.10 - 0.26
CaO	44.36 - 49.45	47.90 - 53.03
Na_2O	-	-
K_2O	-	-
P_2O_5	Trace (5.97)	31.10 - 37.30
CO_2	LDI (38.85 - 43.49)	1.79 - 4.50
H_2O		
S		
F		
Cl		

The chemical analysis of three leached apatite bearing rocks from the Eppawala carbonatite complex are given below.[30]

Constituents	EP/1/P	EP/2/P	EP/3/P
SiO_2	0.50	0.30	0.60
Al_2O_3	0.95	2.23	7.05
FeO	0.70	0.70	0.54
Fe_2O_3	3.72	2.30	7.70
TiO_2	0.78	0.78	0.60
P_2O_5	36.60	36.04	33.00
CaO	52.30	51.60	43.63
MgO	0.20	0.23	0.29
SrO	0.66	0.65	0.60

29/ The Eppawala carbonatite complex, Geological Survey Department Economic Bulletin No. 3.

30/ Analyses by the Geological Survey Department, Colombo, Sri Lanka.

BaO	0.43	0.26	0.62
Na_2O	0.09	0.08	0.19
K_2O	-	-	-
CO_2	-	-	-
F	2.40	2.43	1.74
Cl	0.88	1.04	0.98
U_2O_8	-	-	-
ThO_2	0.02	0.03	0.01
H_2O	1.46	2.65	3.60
Total	101.39	101.32	101.15
Less O for F	1.01	1.10	0.86
Less O for Cl	0.21	0.24	0.22
Total	100.17	99.98	100.07

The mantle of the leached apatite-bearing zone capping the fresh carbonatite with a P_2O_5 content ranging from 31.10% to 37.30% is one of the richest repositories of phosphate in any of the known carbonatite complexes.

The entire exploration programme carried out by the Geological Survey Department, Sri Lanka, was designed to obtain a realistic estimate of the reserves of apatite-bearing rock confined mainly to the upper leached zone of the elevated hill masses. For operational purposes, blocks were marked as A, B, C, D, E, F and G in the northern part of the deposit. The prospecting work was carried out by means of drilling and trenching. An enlarged geological map in the scale of 8 chains to an inch was used as the base map. Altogether, 20 drill holes were sunk to a total footage of 5,183 ft. Drilling investigations are still in progress. The core recovery in many cases was poor, but this is attributed to the unconsolidated nature of the leached apatite-bearing zone. Trenching operations have also been used to estimate the volume of cliff exposure in the leached apatite-bearing zone. Out of the 20 holes, sampling was carried out for the first drill-hole at an average depth of 2 ft. The results indicated variations in P_2O_5 content in the leached apatite-bearing zone. The transition from leached to a fresh carbonatite zone, however, appeared to be very sharp. The leached apatite-bearing zone, rich in apatite, has been punctured in most of the holes. However, most of the drill holes,

because of their placement at the margin of the leached zone, missed the fresh carbonatite and touched directly the basement complex. Drilling in the steep slopes and crest of the hills, blanketed with unconsolidated sediments, made the determination of the true thickness of the leached apatite-bearing zone difficult.

The total proved ore of the Eppawala carbonatite complex (leached ore) is at 25,000,000 tons of which B, C, and D blocks account for 23.23 million tons. The inferred reserves for block A are put at one million tons, and those for E, F and G at 16 million tons. Thus the total proved and inferred reserves for the northern sectors are placed at 40 million tons. After deducting 15 million tons for voids and mining waste, the firm reserve or leached apatite-bearing ore for the northern sector works out to 25 million tons.[31/] Apart from the northern sector of the complex, the deposit extends to south of Yoda-Ela, and this area has not yet been investigated in detail. The Geological Survey Department estimates about 15 million tons in this region.

The leached apatite-bearing zones, despite the erratic variation of P_2O_5 vertically, shows an average grade of 33% P_2O_5. The R_2O_3 content, though appreciably low in the leached apatite zone with high P_2O_5 content, becomes high in the loose unconsolidated clayey fraction. The apatite-bearing rocks show realtively poor citrate solubility. It is found that the solubility is about 20% less than the minimum value recommended for direct application. However, research carried out by various agricultural organizations has indicated that the ground apatite-bearing Eppawala ore is suitable for long-term crops like tea, rubber and coconut.

The leached apatite-bearing elevated zones are covered by a overburden of 10 ft. The carbonatite complex in the northern section of the Eppawala comprising six prominent blocks have a general relief of 150-200 ft, whioh is good for opencast mining. The water-table whioh is at about 50 ft from the valley bottom is not likely to affect the mining operations and is not expected to pose problems of dewatering after mining commences. Mining on a small scale has, in fact, already begun. About 1,300 tons of apatite-bearing

31/ Source: Geological Survey Department.

ore was produced at Eppawala in 1973 by opencast methods of mining. In the two subsequent years production increased to 6,000-7,000 t/y. Mining had to be suspended in 1976 because of accumulation of stocks from the two preceeding years. The production target in the current year in 13,500 tons. The operations employ a little over 300 persons. Jackhammers are used for drilling the rock and blasted rock is transported manually. Oversized chips are broken manually with hammers. Transport to the ball mills is by tractor trailer. The project falls within the jurisdiction of the Anuradhapur District Development Council and is labour-intensive. The ground rock is supplied to the Ceylon Fertilizer Corporation for sale. Production can be stepped up quickly if some degree of mechanization is introduced immediately. Assuming that whatever is produced will be used for the plantation crops, strengthening the grinding capacity will be the next area requiring close attention. Capacity utilization of the currently-installed grinding mills will have to be improved and new ball mills installed to match the increased production. Foreign exchange expenditure on imported rock phosphate could be considerably reduced if prompt measures are taken to maximise production and increase grinding capacity, by both improving capacity utilization and installing new capacity.

The leach apatite-bearing rock will have to be beneficiated before it could be used for the manufacture of superphosphate. The main gangue minerals in the ore are Fe_2O_3 and Al_2O_3. The chloride content of the Eppawala leached apatite rock is also higher than the permissable limits, which will cause serious corrosion problems in the plant equipment. The high fluorine content of the apatite-bearing rock at Eppawala could possibly be removed by high-temperature calcination with silica and steam. The citrate soluble product will be a good source of phospherous for plants in acid soils receiving high rainfall. Another method of defluorination could be by sintering the finely-ground rock phosphate with sodium carbonate and silica in a rotary kiln at very high temperature.

The possibility of manufacturing fused magnesium phosphate from Eppawala ore with serpentine or dolomite has also been considered. The dolomite occurrences in Sri Lanka are reported to be highly variable in character, with magnesium oxide ranges between 4% to 21%. The Geological Survey Department has reported occurrences of serpentine rocks (magnesium silicate) in various parts of Sri Lanka. Recent investigations have indicated high-quality serpentine with around 33% MgO over an area of 250 acres at Ginigalpalessa in the Uda-Walawe

area. No comments, however, can be offered on the above tests, as the results of various experiments were not made available to the mission. In any event, much more exhaustive work will have to done on the beneficiation process before any definite views can be expressed concerning the respective merits of various processes. This area needs immediate attention.

C. United Republic of Tanzania

The rock phosphate deposit at Minjingu was discovered in 1958 by New Consolidated Gold Fields of South Africa, which estimated a reserve of 5 million tons of hard ore and 4.8 million tons of soft ore averaging 21.4% P_2O_5 and 18.5% P_2O_5 respectively. A number of agencies, including Klockner Industries Anlagar GmbH of Germany, Japan Consulting Institute and Geomin of Romania, have since investigated the deposit. Klockner did detailed geological and other work on the deposit and its estimates of ore reserves are more conservative than those of New Consolidated Gold Fields. According to its calculations, the Minjingu deposit has a reserve of 3 million tons of soft ore and 1.3 million tons of hard ore, totalling 4.338 million tons. All the studies, however, confirm the commercial potential of the Minjingu deposit.

According to Klockner, rock phosphate is found in Tanzania in the deposits listed below.[32/]

Deposits of volcanic origin (apatite): Zizi at Big Ruha River; carbonatite deposits of, Sengeri and Ngulla.

Recent guano (hydro collophane): Sakamnera (west of Mbeya), Amboni in the Tanga area, the Isle of Lathan (coal limestone, low in phosphate)

Sedimentary lime phosphate of fossil guano: Pyramid mountains (west of lake Burundi), Minjingu-Kopji (east of lake Manyara).

The deposits of volcanic origin and of recent guano are of no interest because of their limited reserves and low (below 10%) P_2O_5 content. As regards the Pyramid mountains, the phosphate horizons are confined to a small fringe (20-25 m) around the core. Although the P_2O_5 content is reported to be high at certain places these deposits are not economical as the beds soon wedge out. The only reserve that can be economically exploited is at Minjingu.

32/ Source: Klockner report.

Rock phosphate occurs at Minjingu in recent clay-like sediments fringing a large outcrop. The deposit is situated about 5.5 km east of lake Manyara, at 35°55' east of Greenwich and 3°43' south of the equator in the Arasha region. Arasha is the nearest major town (100 km north-east by road). The deposit is 100 km west of the main road from Arasha to Dodoma. The nearest railway station and airport are at Arasha. The only fertiliser plant operating in Tanzania is at Tanga, which is about 420 km from the deposit. Tanga is a seaport.

The width of the deposit is 800 m (WNW-ESE direction) and the length 700 m (ENE-WSW direction). At the foot of Minjingu extends the former bottom of lake Manyara, which was much larger in prehistory and forms with its clayey deposits a vast savannah. Minjingu projects over the surrounding area like an island. The area is almost plane and makes a gently terrace-like descent to the west. There is a pronounced terrace of about 2 m in height in the west of the deposit.

The climate of the Minjingu region is tropical. The temperature ranges between 32°C (maximum) and 14°C (minimum), the annual average being around 32°C. The annual rainfall varies between 16" to 24" (maximum) and 10" to 20" (minimum). The rainy season lasts from December to April. On an average rain falls 54 days in the year. The water supply in the mining area is, however, insufficient.

Studies made by Klockner in September 1970 produced the findings given below.[33/]

Area	Reserves (in tons)	
Northern Zone		
Soft ore	1,730,060	
Hard ore	188,350	
Southern Zone		
Soft ore	1,326,080	
Hard ore	1,093,690	
Totals		
Soft ore	3,056,140	18-20% P_2O_5
Hard ore	1,282,040	18-20% P_2O_5
	4,338,180	

33/ Source: Klockner report on Minjingu.

Phosphate is a replacement type in lacustrine sediments located on a basement of gneisses and schists. There are alternating sequences of beds of 2 m average thickness. The phosphate beds lie at a shallow 6 m average depth beneath the surface. The area surrounding the deposit is open and poses no problem of waste disposal, loading facilities or laying out the dressing plant. Geomin has worked out that for extracting the entire quantity of ore, a total of 1,067,100 tons of pit waste/overburden will have to be removed. Overburden in phosphated beds is 0.251 m^3/t of ore in the northern zone and 0.020 m^3/t of ore in the southern zone. Specific gravity for both hard and soft ore is taken at 2.0 t/m^3. Mining operations will not intersect the water table.[34] There are possibilities of finding more ore if prospecting and development is carried out in the north-east and south.

Analysis of the Minjingu deposit revealed the following chemical composition.[35]

Soft ore	Percentage
Calcium phosphate	70
Carbonates (dolomite and calcite)	10
Quartz and colloidal silica	5-7
Feldspar	3-5
Clay minerals	7
Biotite, Muscovite, Amphibole Pyroxenes, limonite etc.	Minor amounts
Hard ore	
Calcium phosphate	75-80
Quartz and Feldspar	15-20
Limonite, clay minerals and Apatite	Minor amounts (less than 20%)

The mineral content of the untreated ore (x-ray diffraction analysis) includes, in descending order of importance, calcite, quartz, apatite, dolomite and feldspar. Minerals detected by microscope are apatite, calcite, quartz, dolomite,

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34/ General Project on Minjingu Deposit, November, 1974, Geomin, Romania.

35/ Source: Geomin report.

sericite, etc. The general spectral analysis of mixed soft ores is given below.

Range (% by weight)	Elements
10 - 100	Phospherous, silica calcium
1 - 10	Magnesium, iron
.1 - 1	Aluminium, titanium, sodium, potassium, strontium, barium
.01 - .1	Manganese, vanadium yttrium
.001 - .01	Copper, chromium, lanthanium
Traces	Zirconium, nickel, berilium, ytterbium.

Ore-dressing tests on the Minjingu rock have been done by a number of agencies, such as the New Consolidated Gold Fields, Japan Consulting Institute, Klockner, Geomin. Tests were performed by the Mineral Resources Division, Laboratory Services, Dodoma; the Tanzania Fertilizer Company Ltd; and a major company operating in the Florida (United States) phosphate fields. Geomin, in its report of 1974[36/], has confirmed that it is possible to obtain a concentrate of +30% P_2O_5 by a simple crushing and sizing process. Crushing and sizing is also to be used for hard ore, by the product would be for direct application as recommended by ISEC report. Geomin has recommended artificial drying (with a rotary drier) for reducing the moisture content from 16% to around 4%, as air-drying is not sufficient, particularly because of the rainy and winter seasons. The process gives a concentrate of 31.4 % P_2O_5 with 4% moisture. P_2O_5 recovery is 64.1%, and recovery by weight of run of mine ore 56%. In the case of hard ore, weight recovery is 20.4%, and the final product contains 27.71% P_2O_5 30.45% CaO, 19.28% SiO_2 and 4.30% Al_2O_3. Open-cast mining is to be done by deploying small excavators, dumpers, bull dozers, front-end loader, 100 mm-diameter hole drills and other ancillary equipment. The concentrate is to be carried by 25-tonner trucks to the Arasha railway station and from there to Tanga by rail. For direct application, since the material is to move in various directions, no particular mode of transport is recommended. With regard to infrastructure, water and power supply are the two critical areas. The nearest power line is at Arasha. It will have to be diesel-generated on site. Water will have to be brought from a distance, as all boreholes

36/ Source: Geomin report, 1974, made available by STAMICO.

drilled near the deposit have encountered only saline water.

The Geomin study estimates the project to cost $7,600,000 (1974), the production cost of soft ore concentrates being $36.75/t and that of hard ore $30.00/t. After adding 8% profit margin the product could be sold for $39.70 and $32.40 respectively in Tanzania. For providing 100,000 t/y of concentrates from soft ore, 200,000 t/y of crude ore will be needed, and for the same level of production, 120,000 t/y of hard ore will have to be mined, thereby giving a life of 15 years for soft ore and 10 years for hard ore. On the other hand, in view of the smallness of the deposit, the long distance to Tanga, insufficient selectivity and a very high consumption of reagents in the floatation of underslimed material, and the exclusive availibility of saline water at Minjingu, Klockner has suggested the four possibilities described below.[37]

1. Mining of both hard and soft ores; use of both types at a quantity ratio proportional to the reserves of either type in the deposit with separate dressing, separate transport and separate desalting.

2. Mining of only soft ore, removal of hard ore only as overburden and stock-piling it separately near the dressing plant; in a second phase, extension of certain parts of the plant and addition of a floatation plant; in the second phase hard ore to be reclaimed from the stock pile for dressing.

3. Mining of soft ore in the northern part of the deposit and removal of hard ore as overburden; mining of the ore in the southern part is not considered economic as the hard ore is too thick; with the mining capacity required by the Tanga plant, the life of the project would be very short, about three to four years.

4. Mining of soft ore in the northern part but with capacities adopted to the reserves, eg. 50,000 t/y to ensure a maximum life of 10 years; in this case ore is to be used jointly with imported ore in the fertilizer plant.

The structure of the deposit necessitates consideration of these possibilities, as in the northern part of Minjingu soft ore is capped by hard ore. The dividing line between them is formed by marly clay. In the southern part conditions are not so clear, as hard and soft ores are probably intergrown

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37/ Source: Klockner report.

to such a degree that it is impossible to separate them. Klockner concludes that the fourth possibility is the most feasible as the marketability of Minjingu rock improves and a relatively smaller investment is required to start with.

For direct application of the hard ore, the Mlingano Agriculture Research Centre is currently carrying out field experiments and its report is expected shortly. Similar tests carried out by Ukiriguru Agricultual Research Station in the early sixties reported encouraging results.

STAMICO informed the mission that it has completed the feasibility study on the mining and benefication of the Minjingu deposit and expects to take the investment decision within the next three months. The broad outline of the project were not made available to the mission. As a very tentative estimate the project is likely to cost around $9.00 million, of which 70% to 80% will be in foreign currency.[38/] In fact, the entire equipment will have to be imported. Offers to supply equipment (in the nature of a turn-key job) received by STAMICO are being evaluated; no tenders were invited. Benefication will be confined to soft ore only. Since hard-ore benefication would involve comparatively expensive grinding and floatation, STAMICO envisages simple grinding and screening of this ore and its use as low-grade fertilizer by direct application. The capacity envisaged is about 120,000 t/y of concentrates with 200,000 t/y of crude ore. This is with a view to meeting the demand of the Tanga plant at full capacity. Underground sweet water is to be piped from a distance of about 10 km.

The National Industrial Development Corporation (NIDC) has from the demand/supply projections, concluded that there is already surplus capacity in Tanzania even after taking into account projected P_2O_5 demand in 1983. NIDC has therefore ruled out any additional capacity for P_2O_5. The consumption pattern of N, P and K in t/y is shown below.[39/]

Year	N	P	K	Total
1963	1,937	600	1,097	3,634
1968	5,150	3,753	2,325	11,228
1973	11,403	6,184	3,905	21,492

Taking the relevant factors into account, NIDC has projected the following

38/ Source: STAMICO.

39/ Source: Report on Fertiliser Master Plan for Tanzania, 1974, NIDC.

most likely demand for Tanzania by 1983.

Year	N	P	K	Total
1978	25,680	11,232	8,348	45,260
1983	45,642	18,334	13,602	77,578

As against this the supply position would be as shown below.

Year	N	P	K	Total
1978	10,827	28,834	6,375	46,036
1983	11,457	29,098	6,375	46,930

The supply position has been worked out after taking into account the expansion of the Tanga plant, which envisages the addition of 4,200 tons of nitrogen to the existing capacity of 8,530 t/y of N, 30,570 t/y of P_2O_5 and 7,084 t/y of K_2O. The NIDC report suggests peasant-oriented research, development of irrigation facilities, improvement of extension services, better credit facilities, pragmatic pricing policy, integrated agricultural development and other measures to obtain a higher growth rate of fertilizer consumption. Even with the most optimistic estimates the NIDC concluded that P_2O_5 capacity would be higher than the demand in Tanzania even up to 1983. The report did not comment on export possibilities of phosphatic fertilizers for lack of adequate data. It cautioned however, against exports in view of the unpredictable market.

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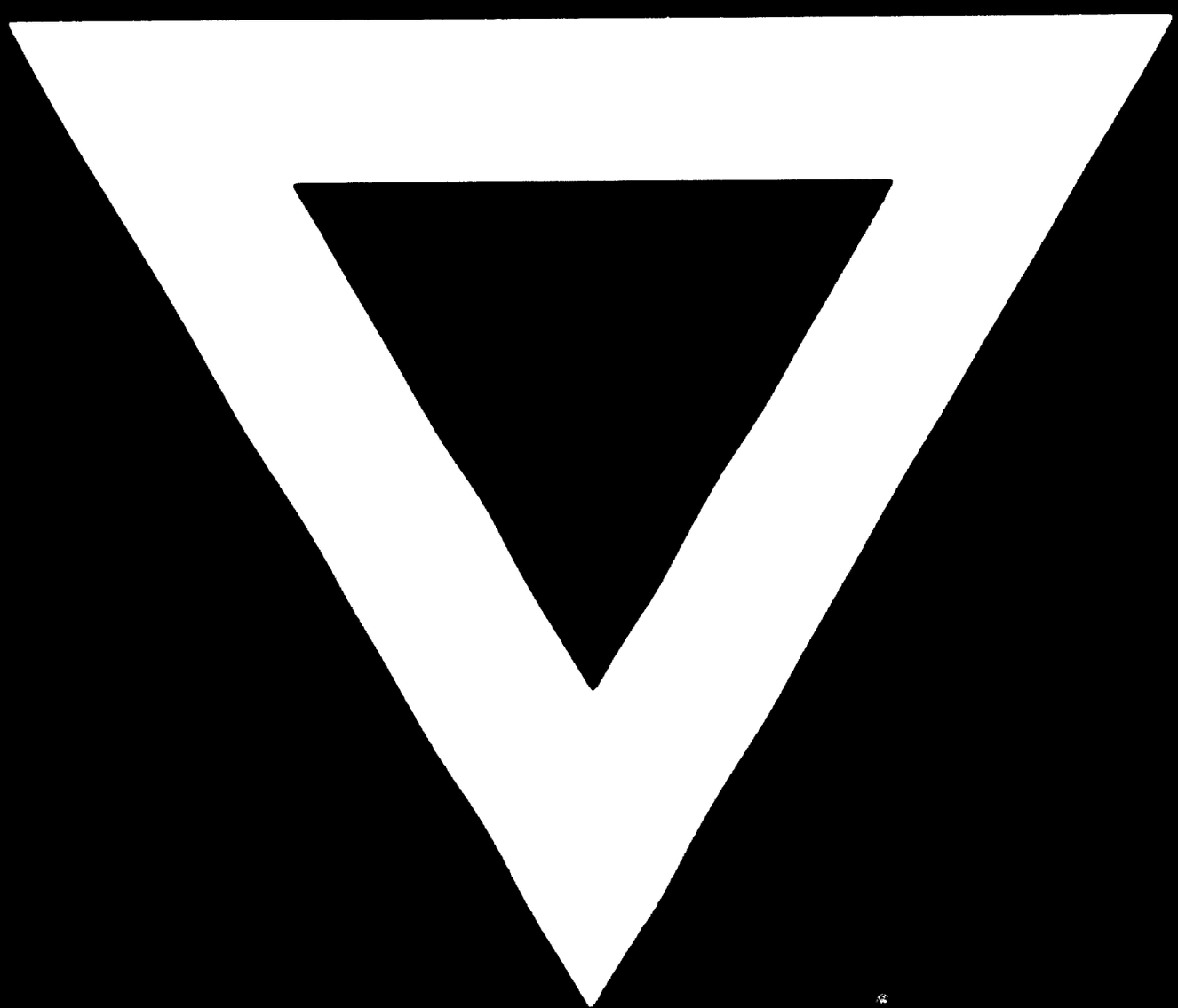

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