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EXPLOITATION AND USE OF LOW GRADE PHOSPHATE ROCK -  
INDIAN EXPERIENCE\*

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SUMMARY

The Indian requirement of phosphatic fertilizers by the end of 90's is in the order of 3.23 million tonnes of  $P_2O_5$  per annum. Indigenous rockphosphate can provide about 0.41 million tonnes of  $P_2O_5$  only, the balance  $P_2O_5$  is to be imported each in the form of rock-phosphate, phosphoric acid or finished phosphatic fertilizer. This requirement is likely to increase further when measures to correct the present imbalance in the consumption of phosphatic fertilizers fructify. The balanced use of N & P is essential not only for crop production but also for maintaining soil fertility.

India has huge reserves of low grade rockphosphate amounting to over 165 million tonnes (excluding 18 million tonnes of directly useable high grade ore of 30%  $P_2O_5$ ). The beneficiation of low grade rockphosphate to produce concentrates suitable for making phosphoric acid/SSP or directly use them as fertilizer either in the same/modified form as non-conventional fertilizers, assumes great importance. The paper describes the efforts made by India in this regard for utilising two major low grade rockphosphate deposits at Jhamarkotra (67 million tonnes) and Mussoorie (45 million tonnes).

### 1.0.0 BACKGROUND

Phosphorus is an essential requirement for balanced use of fertilizers. In the production of phosphatic fertilizers, we require rockphosphate, for which certain quality of rockphosphate is essential. This quality is determined both in terms of  $P_2O_5$  and also other gangue minerals like Silica (not exceeding 2 - 3%) Iron and Aluminium oxide (not exceeding 2-3%) with minimum content of chlorine, organic matter and carbonates.

At present, our food production is about 150 million tonnes per annum for which our consumption of phosphatic fertilizers is of the order of 1.87 million tonnes of  $P_2O_5$  (84-85). The consumption of phosphatic fertilizers is going to increase to 3.23 million tonnes of  $P_2O_5$  by the end of 80's (89-90) to meet the increasing demand of food. This is going to increase further by the end of the century, to meet the increased demand of food required for maintenance and survival of increasing population.

The essential raw material required for the production of phosphatic fertilizers is rockphosphate. Our indigenous production of rockphosphate is 0.83 million tonnes which may increase to about 1.37 million tonnes by the end of 80's. Our indigenous resources will provide 0.41 million

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tonnes of  $P_2O_5$  per annum only and the balance  $P_2O_5$  requirement of about 2.8 million tonnes of  $P_2O_5$ /year has to be met by either using imported rockphosphate, phosphoric acid or finished phosphatic fertilizers.

Our consumption and use of fertilizers at present is not balanced. The present consumption of nitrogenous fertilizers is 5.65 million tonnes whereas phosphatic fertilizer is 1.87 million tonnes  $P_2O_5$ /year / <sup>(N:P:3:1)</sup> The balance proportion of N:P is 2:1. It is well known that if the balance use is not done, it will reduce the crop productivity and also make soils poorer in phosphate content. Soils thus become infertile and are not able to give proper crop yields unless high application of phosphorus is done along with nitrogen. Our Indian soils have low to medium phosphorus status. Thus our requirement of phosphatic fertilizer is going to increase further in future years for maintaining proper crop productivity and soil fertility.

#### 2.0.0 INDIAN RESOURCES OF ROCKPHOSPHATE

India does not possess large reserves of high grade rockphosphate, which totals to only 18 million tonnes. On the other hand there are sizeable reserves of low grade rockphosphate amounting to about 165 million tonnes. Table I gives the position of reserves of Indian rockphosphate along with  $P_2O_5$  content and major impurities. Table 2 shows typical chemical composition of some important rock phosphate occurrence of India. Most of the rockphosphate deposits are in the land lock areas as given in figure I. Thus if they can be put to use, it will reduce the cost of phosphatic fertilizers and encourage the farmers to use the same. Thus it is in this context that optimising the use of low grade rockphosphate

assumes great importance in India, which can be done either by upgrading/beneficiating the rock to improve its quality for using it in the production of phosphatic fertilizers or directly use in the soil or in the modified form to provide a cheaper source of  $P_2O_5$  in the country.

### 3.0.0 BENEFICIATION

The beneficiation of low grade rockphosphate consists in removal of impurities, which is commonly practised in the world. The technique and process however depends on the nature of impurities, mineralogical properties of both apatite and gangue mineral present in the low grade rockphosphate. If such rockphosphate contains apatite minerals associated with the silica or calcite as gangue, these present no difficulty in beneficiation. Even low grade rockphosphate containing 3-4%  $P_2O_5$  are being upgraded to over 35%  $P_2O_5$ . Such commercial size plants are working in Brazil, Finland and other countries.

#### 3.1.0 BENEFICIATION OF INDIAN LOW GRADE ROCKPHOSPHATE

A glance from tables 1 & 2 brings out the fact that chief impurities in most of the Indian phosphorites are carbonates and silica besides hydrated iron oxide. Additionally, pyrite shale and carbonaceous material are also found in some cases to occur as major gangue material. It may not be out of place to mention that the association of carbonates, siliceous and ferruginous impurities with phosphorite is a global phenomenon and to that extent, most of the Indian deposits do not show any departure from the observed trend. However, each and every phosphorite occurrence has some peculiarities of its own in respect to the state of dispersion of phosphate (apatite grains) in the phosphate bed as well as in regard to its textural characteristics.

Table 1 Rock Phosphate Resources in India

Location	Reserve million tonnes	Grade P2O5 percent	Main impurities	Remarks
Rajasthan				
1. Jhamarkotra	17.00	+30	Silica	Exploration by Rajasthan State D&G. Indicated reserve has been placed at 75 million tonnes under exploitation by RSMCL (Product being sold as ACM)
	50.00	12-28	Dolomite	
2. Maton	13.00	22-26	Silica & dolomite	Exploration by GSI. Under exploitation by HZL (used after beneficiation in phosphate acid)
3. Kanpur	10.00	10-17	Dolomite & calcite	Exploration by GSI. Remained unexploited
	1.00	+30		Being mined by RSMCL
4. Karbaria-ka-Gurha, Dakankotra, Sisarma, Meemach Mata, Badgaon, Manoharpura etc.	8.00	5.25	Carbonate silica	Exploration by GSI & D&G. Non-excepting Karbaria and Dakankotra being exploited
5. Pirmania	8.00	10-12	Silica carbonate iron	Exploration by GSI, unexploited
Madhya Pradesh				
6. Jhabua	10.00	29	Silica & partly dolomite	Exploration by GSI, being mined by M.P. Mining Corporation.
	5.00	16.5		
7. Mirapur	3.00	17	Silica, carbonate iron	Exploration by GSI, being mined by M.P. Mining Corporation
Uttar Pradesh				
8. Lalitpur	6.00	15-25	Silica, carbonate iron	Exploration by GSI, being mined by U.P. Mineral Development Corporation.
9. Mussoorie	45.00	20	Carbonate, chert, shale	8.38 million tonnes inferred by GSI, being exploited by PCCL & according to them, the total reserve of inferred & indicated categories is placed at 45.00 million tonnes
West Bengal				
10. Purulia	5.00	About 10% (a portion 25.32%)	Iron	Apatite ore being explored by GSI & exploited by MMIDC
Bihar				
11. Singhbhum	1.00	14-19	Iron	Exploited by Napco.
Andhra Pradesh				
12. Kospatnam	1.00	30-35	Magnetite	Exploited by FCI, A.P. Mining local firm

3.2.0 Efforts undertaken for beneficiation.

3.2.1 Singhbhum Apatite.

The initial effort towards beneficiation of phosphatic ore in India was confined to preliminary lab/bench scale beneficiation tests for the Singhbhum apatite ore, the existence of which was known for a pretty long time. Subsequently, the low grade mixed apatite sample from this area was tested in the pilot plant scale as back as in 1966 in National Metallurgical Laboratory (NML), India. Mineralogically besides apatite, the chief impurities are magnetite, quartz, felspathic and micaceous material, Magnetic separation followed by flotation of non-magnetic fraction are resorted to. The flowsheet developed indicate the possibility of producing a concentrate assaying 41%  $P_2O_5$  with less than 4% total oxide. A general flowsheet based on the above tests was recommended, by NML and which in turn, could be devetailed for a plant to upgrade 150 tonnes per day of apatite ore. Unfortunately in the absence of any serious firm evaluation of the reserve/grade characteristics and apparently small pockety nature of the deposits, NML's above investigation could never be translated into reality.

3.2.2 Purulia Phosphate:

Similiarly for the neighbouring Purulia (Beldih apatite) ore the Project and Development India Ltd. (Planning and Development Division of FCI) is understood to have developed a process, which besides reducing the  $P_2O_5$  content/the said ore, could also reduce the higher chlorine content of the ore. The Project and Development India limited contemplates to undertake pilot plant investigation of the Purulia ore on the basis of the results of their lab-scale finding. Further developments in these regard are awaited.



### 3.2.3 Jhamarkotra Rockphosphate.

Jhamarkotra low grade rockphosphate contains on the average 16%  $P_2O_5$  and have the reserves of over 50 million tonnes. This is metamorphic in origin and belongs to pre-cambrian age ( 570 million year B.C.) containing silica, calcite and dolomite as gangue minerals. In the metamorphic stage, the collaphane phosphatic mineral has crystallised to form apatite crystals. These can thus easily be floated in the beneficiation process.

The typical mineralogical composition indicates that texturally ore is in intimate interlocking arrangement of minute phosphate grains with aphyllised grains of carbonate and for fair liberation a fine mesh of grind is essential.

The beneficiation of this low grade rockphosphate has been done by adopting simple method by subjecting the ground deslimed product to flotation (Silica depression), selective disorption of collector on phosphatic grain in the floated products and further removal of dolomite in froth by depressing phosphate.<sup>(2)</sup> The typical feed and concentrate analysis is shown in table - 3.

Jamarkotra rockphosphate concentrates have been tested and found suitable for production of phosphoric acid and SSP. A pilot plant of 200 tpd has been set up at Jhamarkotra for establishing the above process on large-scale.

### 3.2.4 Maton Rockphosphate.

In the case of siliceous Maton ore, a process of straight flotation of phosphate using sodium oleate as frother cum collector and sodium silicate as depressant has been developed. The above process for floating the apatite has been successfully translated into industrial practice and a plant is smoothly working at Udaipur.

### 3.2.5. Mussoorie rockphosphate deposit.

Another major rockphosphate deposit in India is at Mussoorie, Distt. Dehradun, situated in the outer sub-Himalayan mountains ranges. The deposit occurs in the form of syncline which is about 120 Kms. in length and 13 kms. in width, situated between the altitude of 1000 meters to 2000 metres. Detailed exploration has established an ore reserves of 45 million tonnes upto a depth of 100 metres. The vertical cross section of the deposit shows that the ore body extends to depth, as no borehole at depth has touched the bottom of the syncline, the ore reserves in continuity at depth cannot be ruled out. If so, the ore reserves will rise to over 100 million tonnes.

#### 3.2.5.1 Mineralogical characteristics of Mussoorie Rock-phosphate.

The deposit belongs to cretaceous geological age (136 million year) and is very young. It has not been subjected to metamorphism. The phosphate mineral is collaphane, which is massive and is amorphous to micro-crystalline. Calcite and pyrites are heavily disseminated. The broad mineral qualities are as below:-

##### Mineralogical characteristics.

- Low to medium grade with 15-18% P<sub>2</sub>O<sub>5</sub>.
- Economic Mineral - Carbonate fluoapatite having empirical formula Ca 9.80 Na 0.14 Mg. 0.06 (PO<sub>4</sub>) 5.42 - (CO<sub>3</sub>) 0.58 F 2.23.
- Major diluent - Carbonates (higher calcite, marginally high dolomite) pyrites, silicates in form of quartz with minor amount of clay.
- Textural description: i) Coarse grained spray carbonate and phosphate clasts.  
ii) Fine grained intergrowth of apatite, quartz and carbonate gangue.

The fig. 2 to 8 shows the microscopic structure of this phosphate.

Rock reactivity

Natural Ammonium Citrate (NAC) - Lower values by 2.0 - 2.5% NAC - Soluble P<sub>2</sub>O<sub>5</sub> as compared to sedimentary apatite.

3.2.5.2 Beneficiation

Various attempts have been made to beneficiate the run of mine rockphosphate (ROM RP ) containing 17% P<sub>2</sub>O<sub>5</sub> to produce concentrates containing 28-30% P<sub>2</sub>O<sub>5</sub> which are suitable for chemical processing for production of phosphatic fertilizer. Earlier tests established the beneficiation process of upgrading 28-30% P<sub>2</sub>O<sub>5</sub> by calcination and desliming of the lime. This method of removal of mineral gangue gives a P<sub>2</sub>O<sub>5</sub> recovery of 68 and that too involving high cost. Attempts were made to upgrade Mussoorie rockphosphate by flotation did meet the success. Extensive experiments were made in various Indian laboratories namely; National Metallurgical Laboratory, Jamshedpur, Indian Bureau of Mines Nagpur & Indian Institute of Science, Bangalore, samples of Mussoorie Rockphosphate were also sent abroad for testing in Brazil, USA, Sweden & Italy, but with little success.

Recently PPCL sponsored studies with M/s Sala International, Sweden with the assistance of UNDP/UNIDO. Sala was assigned the job to produce concentrate for Mussoorie Rockphosphate containing 17% P<sub>2</sub>O<sub>5</sub> increasing 28-30% P<sub>2</sub>O<sub>5</sub> suitable for making phosphoric acid/SSP.

After conducting bench scale & pilot plant scale tests on a 100 tonnes sample, Sala concluded that Mussoorie rockphosphate can be upgraded in two steps:

1. Pre-concentration of the Mussoorie rockphosphate from 17% P<sub>2</sub>O<sub>5</sub> to 23-24% P<sub>2</sub>O<sub>5</sub> by heavy media principle, using Dyna Whirl Pool equipment. The main advantage is that the beneficiation is possible on the coarse ore size from 1.0 mm to 20 mm. The product below 1.0 mm is upgraded by desliming the slimes with Hydrocyclone. The concentrates produced both by DWP and Hydrocyclone are mixed which have an average

grade of 20-22% P<sub>2</sub>O<sub>5</sub>, which is the present marketable grade of Mussoorie Rockphosphate. There is high P<sub>2</sub>O<sub>5</sub> recovery of 88% and the cost of processing is also very cheap. <sup>(17)</sup>

2. The pre-concentrate product obtained is upgraded further. The pre-concentrate ore ground fines, 80% passing through 43 micron and subjected to froth flotation. Pilot plant trials conducted by M/s Sala International, Sweden showed that this concentrates can be upgraded to 27-28% P<sub>2</sub>O<sub>5</sub> with P<sub>2</sub>O<sub>5</sub> recovery of 65%, but the re-agent consumption is very high, which makes the step No.2 as un-economic.

In view of this economics of beneficiation of step No.1 and production of concentrates which are marketable it has been decided to set up a pilot plant at Dehradun for firming up the pre-concentration process, using DWP equipment on a large number of samples which will be obtained from various mineable blocks of Mussoorie syncline. This will then establish the process on Mussoorie Rockphosphate even with different mineralogical compositions. The cost of setting up of the Pilot plant under UNDP assistance is US \$ 0.23 million and Government of India Rs.8.8 million (US \$ 0.75 million). The pilot plant is expected to be commissioned by April, 1985.

#### 4.0.0 DIRECT APPLICATION OF ROCKPHOSPHATE.

##### 4.1.0 Characteristics of Rockphosphate for direct application.

Various countries in the world are using finely ground rockphosphate as straight phosphatic fertilizer for various responsive crop and soils. The economic efficiency of the rock depends on various factors such as:

- a) Rock Re-activity - which is dependent on the type of rockphosphate.
  - i) nature of crystalline structure.
  - ii) presence of carbonate substitution in the crystal lattice and
  - iii) association of other nutrients like sulphur micro nutrients, organic matter etc.
  - iv) its physical properties like Amorphous structure
  - v) degree of fineness i.e. particle size etc.
  - vi) porosity of particles.

b) Soil factors.

- i) pH status of the soil
  - ii) P-fixing capacity of the soil
  - iii) P status of the soil - soil low in phosphorus  
increase the dissolution of P from the rockphosphate.
  - iv) calcium: status of soil.  
Study of calcium in the soil also is a drawing force.
  - v) Organic status of the soils: Soils with high  
organic matter provide acid environment for  
dissolution of phosphate rock particle.
- c) Plant factors: plants with long and fibrous roots  
provides large surface area for acidulation of the  
rockphosphate particles, by the organic acid present  
in the root systems. (19)
- ii) Crop duration: Long duration crops require  
slow and steady supply of phosphorus.

Thus in order to obtain acceptable economic efficiency from the use of phosphate rock for direct application, we have to study not only the type of rock being used but also the soil and plant factors as well. On the basis of these factors, it is found that in many situations, the ground phosphate rock provide the same agronomic efficiency as that of water soluble phosphatic fertilizers to many long duration and agriculture crops in acidic soils.

4.2.0 Evaluation of Indian Rockphosphate for direct application.

The chemical characterisation of some of the Indian rocks have been evaluated by various institutions. <sup>(6)</sup> The solubility of Mussoorie rock in neutral solution of ammonium citrate is about 10-12% and Udaipur, rock 2-4%. The solubility of rockphosphate from Mussoorie, Udaipur, Jhabua, Jordan in acid solution has been tested by G.D.Pant University of Agriculture and Technology and the results indicate that behaviour of Mussoorie and Jordan rockphosphate is more or less similiar in regard to calcium and P concentration whereas Jhabua rock gave lowest Ca & P concentration at different pH value. Udaipur rockphosphate stood in between Mussoorie

and Jhabua. P and Ca in solution after 24 hrs. have been shown in fig. 9 & 10 for above rocks. (18)

4.3.0 Suitability of Rockphosphates for direct application in acid soils.

The agronomic evaluations of indigenous rockphosphate have been done for Mussoorie rockphosphate on a large scale (Table 4). In respect of Phosphate Rock some limited work has been done, whilst for other practically little work has been done.

4.4.0 Rockphosphates in neutral and alkaline soils.

In slightly acidic-neutral soils, the phosphate rock will be effective if the P status of the soils is low and some amount of 'P' is present in the available form.

The principal advantage of ground rockphosphate is its low cost, its production require low capital investment, less technical skills, over-all energy requirement is small and can utilise the low grade rock not suitable for production of conventional water soluble phosphatic fertilizers. (13)

The use of direct application of rockphosphate is accounted for only about 4% of phosphatic consumption in the world during 1982-83 (FAO 1983). Out of this only about 20 - 25% was used in Asia mainly in India, Indonesia, Malayasia, Sri Lanka. FAO statistics for China do not include the estimate of about 2 million tonnes of phosphate use for direct application. The use of direct application of rockphosphate has not progressed substantially as the reactive phosphate has not been identified for direct use. When the un-reactive rock finds its way to the farmer and the farmers does not get a proper agronomic efficiency, loses the faith in the use of rockphosphate for direct application.

Further the use of finely ground rock has the draw back of difficulty in handling and application. These difficulties can be minimised by granulating the phosphate rock with water soluble binders which on application in the soil will dis-integrate the granules to disperse the fine rock particles in the soil.

The soils and crop require water soluble source of P205 for its initial root development and other metabolic activities which is needed specially for high yielding varieties of crops grown in the neutral to alkaline soils. Thereafter, the crops further require P205 after about 30 days at the tillerings stage and then the major requirement of P205 comes at the stage of grain formation which is at the end of about 60 days.

Agronomical experiments have been conducted by various Agricultural Universities viz. G.B.Pant University of Agriculture, Pantnagar, CS Azad University of Agri. & Tech., Kanpur, Maryana Agricultural University, Hissar, Banaras Hindu University and UP State Deptt. of Agriculture in which partial substitution of water soluble phosphatic fertilizer has been done to provide about 10%, 20% and 50% substitution of water soluble  $P_{(14)}$  and the balance P205 through Mussoorie Rockphosphate powder. These experiments have been conducted in various crop rotations for a period of two to three years and finally recommended by the State Directorate of Agriculture that the farmers in the State can replace 50% of their P205 requirements by using Mussoorie Rockphosphate powder (tables 5,6,7).

#### 4.5 Limitation of Direct application of Rockphosphate.

The limitation of use of Mussoorie Rockphosphate as powder have noticed as:

1. Long distance of haulage of about 3000-3500 Kms. to Acid soil areas involves lot of transportcost and constraint on the transport system.
2. Difficulties of the farmers in using the powder and applying in the soil.
3. Losses of material in handling and application.
4. Bulk of ore deposit is low grade (16-18% P205) and thus it will not be costly to use this ore after transport over long distance.

In order to overcome the difficulties of direct use of Mussoorie Rockphosphate as fertilizer, PPCL sponsored

studies with the assistance of UNDP/UNIDO. UNIDO commissioned IFDC for conducting the study namely:

5.0.0 Production of modified phosphatic fertilizer directly from low grade Mussoorie rockphosphate.

The aim of the study is to find out the process of using low grade rockphosphate itself as a phosphatic fertilizer with or without processing.<sup>(1)</sup>

5.1.0 Developmental studies by IFDC, USA.

The aims of the studies of IFDC are as below:-

- a) Improve physical properties of direct application product through 'mini-granulation' using suitable binders without impairing the agronomical properties.
- b) Develop suitable process of Partial Acidulation of rock to convert the phosphate contained to more soluble form for plant availability.
- c) study the agronomical efficiency of developed products i.e. mini-granulation with different water soluble binders in the green house and laboratory soil incubation followed by field trials in India under different agro-climatic conditions, soils and crops.

5.2.0 Mini-granulation studies.

Studies were done using different water soluble binders so that on the application of mini-granulation in the soil, the PR particles revert to original form after the water soluble binder is dissolved in the soil.

The flow diagram of process adopted is depicted in fig. 11

The various steps adopted are granulation, drying, screening, crushing and re-cycling of under-sized material to process stream.

The various binders used are:

- i) Saturated Potassium Chloride solution prepared from commercial KCl.
- ii) Urea - 50% soln. at 105°C.
- iii) Sulphuric acid -50% soln.
- iv) Phosphoric acid -40% soln.
- v) Mixture of 40% urea soln. and 2% nitric acid.



The various parameter studies are:

- a) Pinmix speed
- b) Product characteristics and handling problem during various process steps and recycle ratio for good mini-granulation.

Size of the mini-granules produced - (-) 48 + 100 mesh  
or (-) 0.300+0.106 mm

#### 5.2.1 Results & Discussion:

Summary of operating data correlating process parameters like binder type, temp. recycle ration etc. shown in Table 8.

- Physical properties of product shown in Table - 9.  
Physical & handling properties (especially-dustiness) can be considerably improved through mini-granulation with different binders (Urea, KCl,  $H_2SO_4$ ,  $H_3PO_4$ , Urea +  $HNO_3$ ).
- From operational/maintenance view point binders like KCl,  $H_2SO_4$ ,  $H_3PO_4$  are most attractive.
- Virtually no change in available P2O5 of product with respect to original rock irrespective of type of binder. The binders such as sulphuric acid and phosphoric acid increases the available P2O5 substantially.<sup>(4)</sup>

#### 6.0.0 Partial Acidulation/Granulation studies (PAPR)

##### 6.1.0 Principle.

The basic principle of process is controlled acidulation condition, which selectively attack the calcium phosphate -minimising dissolution of undesirable elements like iron and alumina, resulting in product with desired level of available phosphate, low free acid and good physical properties. (1,3,7,8,15,16)

The chemistry of PAPR using sulphuric/phosphoric acid is similar to SSP/TSP production.

Like SSP/TSP water soluble compound in PAPR is mono-calcium phosphate mono-hydrate, the other compounds include di-calcium phosphate, dihydrate, calcium sulphate, calcium/iron/aluminium phosphates and inert materials as present in the rock.<sup>(9a)</sup>

### 6.2.0 Process

The flow diagram and process for production of PAPR is depicted in Fig. 12

The studies were conducted on three different types of following material:

1. ROM
2. Attrition scrubbed ROM in acid medium to remove carbonates ( a step by beneficiation process)
3. Pre-concentrates produced by Sala International, Sweden based on heavy media separation.

- The reason for these studies are to compare the properties of product and economics of processing.

Different type of granulators like pin mixer, pug mill were tried to see the operational/maintenance problem and physical properties. Pug mill have an edge over pin mixer in case of Mussoorie Rock.

Various parameters studied are :

- 1) Various types of binders i.e.
  - a) Pot chloride
  - b) phosphoric acid.
- 2) Granulation speed
- 3) different acids and their concentration i.e.
  - a) H<sub>2</sub>SO<sub>4</sub> - 73%, 83%, 93% b) Phosphoric acid: 54%
- 4) Re-cycle ratio and
- 5) physical properties of product.

- Size of product produced - Det. 3.35 and 0.212 mm.

### 6.3.0 Discussion of results. <sup>6)</sup> Analysis of various PAPR products is shown in Table No. 9A.

#### 1. ROM

- SSAG process using ROM Mussoorie rock and Sulphuric acid of 73%, 93% are difficult to control at 50% product water solubility due to stickness consisting build up in different process steps. Acid quantity reduction improves operation but deteriorates physical properties. <sup>(h)</sup>
- Acidulation with Phos. acid is smooth and simple. To achieve 50% product water solubility, about 56% P205 to be derived from Phos. acid, which is mainly imported.

2. Attrition-Scrubbed material.

- Attrition scrubbed material with 5% nitric acid soln is well suited for SSAG process either using sulphuric or phos acid. Acid consumption is comparatively low due to lower carbonate content.
- Water solubility of total P<sub>2</sub>O<sub>5</sub> is 43.2% and 48.2% respectively with phos and sulphuric acid with enhanced physical properties.

3. Pre-concentrate from SALA International.

- Pre-concentrate produced using heavy media technique is reasonably easy to acidulate with 83% sulphuric acid for a product containing 50% water solubility. Operation control is difficult in higher acid concentration, the physical properties of produced material are excellent.
- This heavy media pre-concentrate is also suitable for production of PAPR in ROP (Run of Pile) from which is semi-granular and non dusty with 59% available P<sub>2</sub>O<sub>5</sub>. This ROP, PAPR process is relatively simple and product is likely to be cheaper. Detailed parameters for investment/production cost are needed.

7.0 Agronomical studies.

The above experimental material prepared were agronomically tested for its efficiency. The following procedure was adopted for conducting these tests.

- 1) Laboratory soil incubation study.
- 2) Green house studies at IFDC.
- 3) Field agronomic trials in India.

7.1.0 Laboratory soil incubation study.

The objective of the laboratory incubation study was to investigate the effectiveness of various PAPR formulations (from Mussoorie Phosphate rock) (1) to provide available 'P' in some typical Indian soils and (2) study soil and product properties as related to the available 'P' provided by the Mussoorie Phosphate rock products in the soils. In the soils incubation study, commercial TSP was also included for comparison. (5)

In addition to above incubation studies green house evaluation was done in equivalent US. soils.

The laboratory incubation study showed that the amount of Bray P-1 extractable P from various Mussoorie PAPR products compared well, with that obtained from the TSP. The details are given in tables 10, 11, 12. It will be seen from the results that the Mussoorie PAPR products are effective in providing available P as comparable to that of TSP.<sup>(5)</sup>

#### 7.2.0 Green house studies.

The specific objectives of the green house studies were:

- 1) to determine the relative capacity of the sources of Mussoorie PAPR in question to supply plant available phosphorus under stressful growing conditions and
- 2) to determine the relationship between this capacity and soil test measurements as a means of predicting source potential in different soils.

In each trial, product efficiency was measured by (1) plant response to P, (2) uptake of P by the maize plant, (3) chemical extraction to estimate plant available P in the soil following cropping.<sup>(5)</sup>

It can be observed (Table 13) that there was no significant difference between TSP and of the 50%  $H_3PO_4$  product formulation. The  $H_2SO_4$  PAPR was both significantly less effective than TSP or 50%  $H_3PO_4$  PAPR but again showed potential to positively increase crop production with increasing rates of application. To predict the RAE values of the Mussoorie products on the Indian soils, the relative Bray P-1 extractable P in an Indian soil treated with a given Mussoorie Product after a 3 week incubation period was first calculated. Table 14 shows the predicted RAE values of various Mussoorie PAPR products on four Indian soils.

It may, therefore, be concluded from the Green house trials and laboratory incubation studies that partial acidulation of the Mussoorie PR at 40%-50% with either  $H_2SO_4$  or  $H_3PO_4$  seems to have produced good P-fertilizers for the Indian soils. In Srinaketan (West Bengal) soil, the predicted RAE values of Mussoorie PAPR ranged from approximately 75% to 96% as compared with TSP. For Ranchi soil, the predicted RAE values were all equal or greater than 100% as compared with TSP.

#### 7.3.0 Agronomical trials in India.

In order to evaluate the agronomic efficiency of Mussoorie PAPR, it was decided by PPCL to undertake field trials with the various PAPR products in the neutral soil areas to northern and eastern region of India under the supervision of the following Agricultural Universities (1) G B Pant University of Agriculture and Technology, Pantnagar (U.P), (2) C.S.Azad University of Agriculture & Technology, Kanpur, (3) Orissa University of Agriculture & Technology, Bhubaneshwar. The typical soil characteristics are given in Table 15.

##### 1) Bhubaneshwar.

The field trial was carried out in a soil having pH 6.2, the soil has low in available 'P' and high 'P' fixing capacity. It was observed that there was no significant difference between various source of P as compared to TSP the variation being  $\pm 2\%$ . Higher yields were, however, obtained with 50%  $H_3PO_4$ , 25%  $H_3PO_4$  gives slightly less yield in direct crop (Table - 16).

##### 2) C.S.Azad University of Agriculture, Kanpur.

The tests were done in the soil with pH at 7.85 with low 'P' status and low P fixing capacity. The results show that as compared to TSP, the variations with

50%  $H_2SO_4$  are superior to all the products, followed by 50%  $H_3PO_4$  (C). The results of 25%  $H_3PO_4$  (C) are also very promising (Table - 17).

3) G.B.Pant University of Agriculture & Techn., Pantnagar.

The field trial results show 50%  $H_3PO_4$  PAPER is at par with TSP. Even 25%  $H_3PO_4$  PAPER prepared is comparable with TSP. These results have been obtained with direct (kharif) residual (Rabi) crop as well as also with direct Rabi crop (Table 18).

8.0 Production of other forms of fertilizer from low grade rock.

8.1.0 Production of liquid form of nitro-phosphates, directly from low grade Mussoorie Rockphosphate.

This process envisages the solubilization of low grade rockphosphate, with weak nitric acid produced in the nitrogen arc-reactor which oxidises the nitrogen and oxygen from air. This has been developed by M/s Battelle C.F. Kettering Research Laboratory, USA. This weak nitric acid is recycled and pumped over a column containing bed of low grade Rockphosphate Chips (12 mm size). The part of nitric acid is fixed with calcium carbonate as calcium nitrate and the balance nitric acid converts the rockphosphate to Mono-calcine phosphate. Both calcium nitrate & Mono calcium phosphate are soluble in water. This liquid fertilizer is cycled and re-cycled over the bed of rockphosphate to concentrate the fertilizer contained in the liquid. This liquid N.P. fertilizer as produced is stored and applied to the crops.

Studies have been commissioned for the methodology of application of this fertilizer and its agronomical efficiency. The studies have shown that NP liquid fertilizer is as agronomical efficient as the solid fertilizers.

The above small Electric Arc Reactor requires only 4-5 KW for electrical energy. This small quantum of electrical energy can be easily generated in mini-hydroelectric generators, wind mill generator, or solar photo electric cell generators. The location of such units in remote areas will provide a reliable and dependable source of fertilizer which avoid the transport of N.P. fertilizer over long distance, excepting some rockphosphate. This one unit

is sufficient to produce fertilizer requirement of about 2 hector farm.

9. Economics

The economic use of thermal phosphate has not been critically evaluated but in view of requirement of energy which is very costly and the low value of the product, the cost effectiveness of use of this thermal phosphate is not expected to be attractive.

The cost of utilising the ground rockphosphate by the farmers is about 60% as that of P<sub>2</sub>O<sub>5</sub> from water soluble P fertilizers. The use of this ground Mussoorie rock requires transportation over a long distance to the acidic soils areas situated in Southern and North-Eastern States. In view of the low efficiency of utilisation in the Indo-gangetic neutral to alkaline soil areas they can be utilised to the extent of 50% of the requirement if they are granulated along with the water soluble P fertilizers so that the farmers can make large-scale application.

The use of Mussoorie PAPR has been tested and this provides a satisfactory alternative to 100% water soluble P fertilizers. The use of the acid in partially converting the P<sub>2</sub>O<sub>5</sub> in the rock in the available form can fetch extra sales realisation, which may be almost sufficient to look after the extra cost of acid and the cost of the process. However, detailed economic study is being done.

10.0 Conclusions

Phosphorus is an essential nutrient to be supplied through balanced fe-tilisation for achieving a successful crop production. Our requirement of phosphorus is expected to come to 3.23million tonnes P<sub>2</sub>O<sub>5</sub> by the end of 90's. Exploitation of our existing indigenous rockphosphate will provide only 0.41million tonnes of P<sub>2</sub>O<sub>5</sub> per year. Thus the balance 2.8million tonnes of P<sub>2</sub>O<sub>5</sub> will have to be imported.

We have over 165 million tonnes of low grade rock-phosphate (16%  $P_2O_5$ ) i.e. about 26 million tonnes  $P_2O_5$ . The use of suitable low grade rockphosphate as a source of  $P_2O_5$  requirement can provide substantial indigenous resources.

The low grade rockphosphate can be used in powder form for direct application. This is possible only with these rocks which are re-active and agronomically suitable and use of which has been established. In case of other rockphosphates, they can be utilised by preparing non-conventional fertilizers like Partially Acidulated Phosphate Rock (PAPR) or liquid fertilizer. <sup>(12)</sup> Agronomical efficiency of PAPR prepared from Mussoorie Rock by IFDC, USA has been tested by laboratory incubation studies, green house studies and also field trials and all the results have shown that this is able to meet the 'P' requirement of the crop & even 25% PAPR compares fairly well with the agronomic efficiency of water soluble phosphatic fertilizer. <sup>(9,10,11)</sup> Thus by adopting the above approach, we can provide not only cheapest source of  $P_2O_5$  for our crop, but also will be able to provide indigenous resource for reducing our requirement of imports.

#### 11. Acknowledgements

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Table 2 - Chemical composition of some important rock phosphate occurrences of India

Constituent	Phosphorite					Apatite							
	Rajasthan					Uttar Pradesh			Madhya Pradesh		West Bengal	Bihar	Andhra Pradesh
	Jhankotra		Maton	Kanpur		Mussoorie		Lalitpur	Hirapur	Jhabua	Purulia	Singbhum	Kasbapatnam
	High grade	Low grade	High grade	Low grade	Birmania	Medium grade	Low grade			High grade	High grade	Low grade	High grade
P <sub>2</sub> O <sub>5</sub>	30-37	14-26	30-32 (22-26 lg)	16.4	12.62	23.32	19.74	15-20	17.33	31.57	31.30	17.34	36.95
CaO	46-52	38-44	43.48	43.0	26.29	40.23	42.64			42.14	43.33	26.45	47.62
MgO	0.5-3	6-12	0.76	9.2	nd	4.50	1.00			0.73	0.50	2.30	1.12
SiO <sub>2</sub>	5-12	5-10	18.52	4.6	21.11	8.20	8.81			14.48	2.91	20.92	5.52
R <sub>2</sub> O <sub>3</sub>	1-3	1-4	11.63	0.2	12.68	6.79	3.6			3.27	26.81	23.06	6.51
F	2-3	1.5-2.5	1.22	1.0	nd	1.05	nd			2.78	3.04	1.60	2.90
Cl	100ppm	100ppm	nd	nd	nd	nd	nd			0.06	nd	0.09	0.42
LOI	1-2	20-25	1.63	25.0	16.06	nd	14.06			1.52	9.58	4.26	1.09

nd—Not detectable

lg—Low grade

t—Result of a typical analysis

Table 3 - Typical Chemical Analysis of Jhamerkotra Rock Phosphate  
and Concentrate Sample

	ORE TYPES TESTED		
From Blocks	D	C	B
<u>Feed (Average)</u>			
P <sub>2</sub> O <sub>5</sub>	16 - 17	18 - 20	11 - 13
SiO <sub>2</sub>	2 - 4	2 - 4	2 - 4
MgO	12 - 13	3 - 10	13 - 15
<u>Concentrate</u>			
P <sub>2</sub> O <sub>5</sub>	34 - 36	34 - 36	34 - 36
SiO <sub>2</sub>	4 - 6	4 - 6	4 - 5
MgO	1.4	1.4	1.8-1.9

Table No.4 - Results of filed trials/demonstrations conducted with Mussoorie Rock on paddy crop in acid soil (1975-76 & 1976-77)

Area/State	No. of trials demonstrations	Average grain yield in q/ha			Efficiency of Mussoorie rock phosphate as compared to water soluble phosphate taken as 100
		Without P205	P205 from water soluble sources	P205 from Mussoorie rock phosphate	
1. Assam	82	46.45	63.85	56.05	104
2. Chottanagpur (Bihar)	40	N.A.	37.15	39.56	106
3. Orissa	9	29.86	31.17	31.24	100
4. Orissa	78	N.A.	33.20	35.23	106
5. West Bengal	119	N.A.	34.13	36.46	107
6. Western Ghats	301	N.A.	40.14	42.23	105

N.A. Not available

Note A.P.K. have been applied at the doses recommended by concerned State Deptt. of Agriculture.

Table - 5 Results of the agronomical trials  
in wheat in neutral soils

Locations	No. of trials	Yield data in q/ha		
		Control (NK alone)	SSP	SSP+MP (Mixture)
Pantnagar (UP) 1974-75	-	29.5 (Residual after maize)	48.4	50.5
Patharchata (Pantnagar)	-	20.0 (Residual after maize)	51.3	41.0
University Farm (Pantnagar) (UP) 1974-76	2	22.0 (Mean of two experiments)	53.1	50.0
Doiwala (Dehradun) (UP) 1975-76	7	-	43.2	43.0
Test demonstrations (UP) 1975-80	110	- (Large scale trials)	34.6	36.1
Regional Research Stations (UP) 1976-77	7	34.64	39.36	39.26

Table 6 - Results of field trials at Bihar, U.P. and M.P. in Paddy in neutral soils

Location	No. of trials	Yield data in q/ha		
		Control (NK alone)	SSP	SSP+MP mixture
Nagina (UP) 1974-75	-	22.57	33.77	33.07
Patharchata (Pantnagar) (UP) 1976-77	-	21.3 (Residual after wheat)	36.4	36.1
Test Demonstrations (UP) 1977-81	-	36.1 (Residual after wheat)	63.8	62.2
		28.80 (Residual after potato)	47.03	47.33
	93	-	32.39	34.13
Regional Research Stations (UP) 1975-76	7	35.32	40.46	40.17
Test demonstration (MP) 1979-80	2	20.89	40.35	39.05
Motipur (Muzaffarpur) (Bihar) 1982-83	1	18.20	21.20	21.80

Table No. 7 Results of the trial on sugar cane  
in neutral soils of U.P.

Location	No. of trials	Yield of cane q/ha	
		SSP	SSP+MP Mixture
Doiwala (Dehradun) UP 1975-76	10	957.6	996.0

(Over a basal of N & K)

Table 8

Summary of Operating Data--Miscellaneous of Run-of-Mine, As-Received, Ground Masses of Phosphate Rock in the Continuous Laboratory-Size Granulation Unit

Test number	MSR 105-AA	MSR 200-A	MSR 301	MSR 400-A	MSR 501-A
<b>Binder type</b>	Urea	Potassium chloride	Sulfuric acid	Phosphoric acid <sup>a</sup>	Urea + nitric acid
Binder concentration, wt %	50	13.5	50	60	40, 2 <sup>b</sup>
Actual production rate, kg/hour <sup>d</sup>	11.02	11.49	17.30	11.11	14.48
<b>Pulvisizer</b>					
Rock feed rate, kg/hour	12.17	12.11	18.36	11.96	15.28
Binder feed rate, kg/hour	1.92	3.0	3.25	2.48	1.686
Water feed rate, kg/hour	0.45	3.21	1.3	1.5	-
Nitric acid feed rate (2% by weight), kg/hour	-	-	-	-	1.05
Temperature of binder, °C	105	25	25	-	105
Recycle feed rate, kg/hour	14.00	18.24	9.19	18.02	15.29
Recycle ratio, kg/kg	1.08	1.45	0.46	1.4	0.95
Temperature of recycle, °C	27	27	27	27	27
<b>Particle size of recycle:</b>					
Oversize (larger than 0.295 mm [48 mesh, Tyler]), %	0	0	0	0	0
Product (between 0.106 and 0.295 mm [148 + 150 mesh, Tyler]), %	13.4	14.8	15.5	16.7	25.5
Undersize (smaller than 0.106 mm [150 mesh, Tyler])	86.6	85.2	84.5	83.3	74.5
Discharge temperature, °C	76	76	52	44	60
Average revolution, rpm; tip speed (m/second)	1,000; 6.4	870; 5.6	840; 5.4	850; 5.4	850; 5.4
Discharge moisture content, %	3.5	4.5	7.5	7.5	5.5
Average pin wear, mm/kg of product	0.26	0.21	0.066	0.034	0.26
Power consumption, kWh/mt of product	45	56	35	50	40
<b>Dryer</b>					
Angle, degree	2.5	2.5	2.5	2.5	2.5
Revolution, rpm	6	6	6	6	6
Air discharge temperature, °C	85	74	70	65	60
Material discharge temperature, °C	75	66	64	57	60
<b>Analysis of Product</b>					
Total P <sub>2</sub> O <sub>5</sub> , %	16.8	16.5	15.0	24.0	16.4
Water-soluble P <sub>2</sub> O <sub>5</sub> , %	-	-	0.3	0.9	-
Available P <sub>2</sub> O <sub>5</sub> , % <sup>g</sup>	0.3	0.3	0.8	4.9	0.4
Free acid, %	-	-	0.0	0.1	-
H, %	2.6	-	-	-	2.6
H <sub>2</sub> O, %	-	2.8	-	-	-
Moisture, % <sup>i</sup>	<1.0	<1.0	<1.0	<1.0	<1.0
Availability, % of total P <sub>2</sub> O <sub>5</sub>	1.8	1.8	5.0	20.0	2.4
<b>Raw Materials Consumption</b>					
Urea:product ratio <sup>j</sup>	0.073	-	-	-	0.050
Potassium chloride:product ratio <sup>j</sup>	-	0.032	-	-	-
Sulfuric acid:product ratio <sup>j</sup>	-	-	0.076	-	-
Phosphoric acid:product ratio <sup>j</sup>	-	-	-	0.106	-
Nitric acid:product ratio <sup>j</sup>	-	-	-	-	0.002
Rock:product ratio	0.927	0.960	0.965	0.923	0.948

a. Wet-process acid.  
 b. Expressed as P<sub>2</sub>O<sub>5</sub>.  
 c. 48% urea and 2% nitric acid.  
 d. Due to loss of material during in-process handling, the actual production rate is lower when compared with the feed rate of raw materials (phosphate rock and binder).  
 e. Defined as the weight ratio of total recycle to phosphate rock plus binder fed to the pulvisizer on a dry basis. Under ideal operating conditions, this ratio would correspond to the recycle fed to the granulator and the amount of product produced.  
 f. Approximate. Relative to empty pulvisizer operation.  
 g. Expressed as summation of water-soluble and citrate-soluble P<sub>2</sub>O<sub>5</sub>, where citrate-soluble P<sub>2</sub>O<sub>5</sub> is measured by ADAC neutral ammonium-citrate method.  
 h. Expressed as P<sub>2</sub>O<sub>5</sub>.  
 i. ADAC vacuum distillation method.  
 j. Based on 100% binder concentration (i.e., urea, KCl, H<sub>2</sub>SO<sub>4</sub>, H<sub>3</sub>PO<sub>4</sub>, HNO<sub>3</sub>).



Physical Properties of Minigranulated Products Prepared From Run-of-Mine, As-Received, Ground Mussoorie Phosphate Rock<sup>a</sup>

Table 9

Binder Type <sup>c</sup>	Bulk Density <sup>d</sup>		Angle of Repose <sup>e</sup> (degree)	Porosity (%)	Abrasion Resistance, % Degradation <sup>f</sup>	Disintegration in Water	
	kg/m <sup>3</sup>	lb/ft <sup>3</sup>				5 minutes (%)	15 minutes (%)
Urea	1,111	69.4	30.0	4.3	8.0	73	78
Potassium chloride	1,122	70.1	28.5	4.3	13.1	84	85
Sulfuric acid	1,132	70.7	32.0	5.9	6.5	18	47
Phosphoric acid	1,076	67.2	32.0	2.5	11.3	3	3
Urea plus nitric acid	1,065	66.5	32.0	4.3	6.8	89	89

a. Porosity and disintegration in water were determined according to the procedure developed by IFDC; all other tests were performed according to the procedures outlined in the TVA Special Report No. S-444 (8).

c. Refer to Table 8 for binder concentration in the product.

d. Bulk density of finely ground Mussoorie phosphate rock--1,290 kg/m<sup>3</sup> (80.6 lb/ft<sup>3</sup>).

e. Angle of repose of finely ground Mussoorie phosphate rock--42°.

f. Under simulated handling.

Hygroscopicity of Minigranulated Products Prepared From Run-of-Mine, As-Received, Ground Mussoorie Phosphate Rock

Binder Type <sup>c</sup>	Hygroscopicity (72 Hours' Exposure Time at 80% Relative Humidity and 30°C)				Physical Condition <sup>d</sup>
	Moisture Absorption (mg/cm <sup>2</sup> )	Moisture Penetration (cm)	Moisture-Holding Capacity (mg/cm <sup>3</sup> )	Moisture-Holding Capacity (%)	
Urea	96.5	1.0	96.5	8.6	(A) Damp with light-to-medium set after 48 hours (B) Same as A
Potassium chloride	61.7	0.0	- <sup>e</sup>	- <sup>e</sup>	(A) Dry with very light set after 48 hours (B) Same as A
Sulfuric acid	24.1	0.0	- <sup>e</sup>	- <sup>e</sup>	(A) Dry and free flowing (B) Same as A
Phosphoric acid	5.4	0.0	- <sup>e</sup>	- <sup>e</sup>	(A) Dry and free flowing (B) Same as A
Urea plus nitric acid	123.3	2.6	47.4	4.3	(A) Damp with medium set after 48 hours (B) Same as A

a. Determined according to the procedure outlined in TVA Special Report No. S-444 (8).

b. Refer to table 8 for binder concentration in the product.

d. Condition: (A) periodically checked during the test period; (B) checked after test period.

e. Moisture-holding capacity cannot be calculated without some evidence of moisture penetration.

Table - 9 A Analysis of various PAPR Products prepared from Mussoorie Rock Phosphate

Type of Material	Acidulation Type	% <sup>a</sup>	Total P <sub>2</sub> O <sub>5</sub>	W.S. P <sub>2</sub> O <sub>5</sub>	C.S. P <sub>2</sub> O <sub>5</sub> % <sup>b</sup>
40% H <sub>2</sub> SO <sub>4</sub> PAPR (AR)	H <sub>2</sub> SO <sub>4</sub>	40	13.9	4.5	0.2
50% H <sub>3</sub> PO <sub>4</sub> PAPR (AR)	H <sub>3</sub> PO <sub>4</sub>	50	32.6	15.5	4.1
25% H <sub>3</sub> PO <sub>4</sub> PAPR (AR)	H <sub>3</sub> PO <sub>4</sub>	25	26.5	3.6	8.1
50% H <sub>3</sub> PO <sub>4</sub> PAPR (C)	H <sub>3</sub> PO <sub>4</sub>	50	30.3	13.1	4.3
50% H <sub>2</sub> SO <sub>4</sub> (C)	H <sub>2</sub> SO <sub>4</sub>	50	17.6	8.5	1.9

a. Indicates percentage of acid required to produce SSP.

AR as - received rock.

C Concentrate

e Neutral ammonium citrat soluble P<sub>2</sub>O<sub>5</sub> (AOAC procedure).

Table 10 Bray-1 Extractable P in Windthorst Soil Treated with 200 ppm P during Incubation (ppm)

Treatment	Incubation Time, Weeks			
	0	1	3	10
PAPR (40% H <sub>2</sub> SO <sub>4</sub> ) (AR)	1.16	1.13	1.09	1.13
PAPR (50% H <sub>3</sub> PO <sub>4</sub> ) (AR)	2.41	2.36	2.67	2.50
PAPR (50% H <sub>3</sub> PO <sub>4</sub> ) (C)	1.69	1.84	1.85	2.03
PAPR (50% H <sub>2</sub> SO <sub>4</sub> ) (C)	1.33	1.28	1.39	1.24
TSP	2.91	2.83	3.18	3.85
Check (no P)	0.02	0	0	0

Table 11 Bray-1 Extractable P in Ranchi Soil Treated With 200 ppm P During Incubation (ppm)

Treatment	Incubation Time, Weeks			
	0	1	3	10
PAPR (40% H <sub>2</sub> SO <sub>4</sub> ), (AR)	38.6	22.4	4.75	4.11
PAPR (50% H <sub>3</sub> PO <sub>4</sub> ), (AR)	62.4	20.4	4.07	6.70
PAPR (50% H <sub>3</sub> PO <sub>4</sub> ), (C)	52.1	27.5	6.70	0.43
PAPR (50% H <sub>2</sub> SO <sub>4</sub> ), (C)	41.0	23.0	14.0	3.65
TSP	66.5	20.8	2.14	2.45
Check (No P)	0.03	0.06	0.09	0

Table 12 Bray-1 Extractable P in Sriniketan Soil Treated with 200 ppm P During Incubation (ppm)

Treatment	Incubation Time in Weeks			
	0	1	3	10
PAPR (40% H <sub>2</sub> SO <sub>4</sub> ), AR	40.7	25.2	18.7	6.73
PAPR (50% H <sub>3</sub> PO <sub>4</sub> ), AR	65.0	46.4	26.7	3.23
PAPR (50% H <sub>3</sub> PO <sub>4</sub> ), (C)	53.3	37.2	11.6	2.72
PAPR (50% H <sub>2</sub> SO <sub>4</sub> ), (C)	48.3	29.3	22.0	4.35
TSP	97.3	53.6	32.9	19.5
Check (No P)	0.08	0.02	0.02	0.01

Table 13 - Predicted Relative Agronomic Effectiveness (RAE) of Various Mussoorie PAPR Products on Indian Soils

Treatment	Predicted RAE			
	Allepey	Coorg	Ranchi	Sriniketan
PAPR-40% H <sub>2</sub> SO <sub>4</sub> (AR)	-	-	≥ 100	90
PAPR-50% H <sub>3</sub> PO <sub>4</sub> (AR)	-	-	≥ 100	96
PAPR-50% H <sub>3</sub> PO <sub>4</sub> (C)	-	-	≥ 100	75
PAPR-50% H <sub>2</sub> SO <sub>4</sub> (C)	-	-	≥ 100	93

AR - As Received Rock

C - Concentrate.

Table 14 - Dry Matter Production of Maize from Missoorie PR Products During  
Two Cropping Periods (g/pot)

Windthorst Soil (pH 6.32), U.S.A.

Treatments	Rate of Application (ppm P)											
	Crop 1					Crop 2						
	0	50	100	200	400	Mean	0	50	100	200	400	Mean
Check	2.10					2.10	1.50					1.50
TSP		10.44	12.11	13.42	12.58	12.14		4.69	10.08	20.25	23.83	14.71
40% H <sub>2</sub> SO <sub>4</sub> AR		5.88	8.30	11.11	11.90	9.30		3.94	7.42	10.60	18.82	10.20
50% H <sub>3</sub> PO <sub>4</sub> AR		7.97	11.65	12.39	14.41	11.61		7.37	12.52	15.67	21.78	14.34
50% H <sub>3</sub> PO <sub>4</sub> C		9.46	10.26	12.09	13.00	11.20		4.26	7.83	12.99	22.70	11.95
50% H <sub>2</sub> SO <sub>4</sub> C		7.20	10.35	11.52	12.23	10.33		5.39	9.07	12.65	21.14	12.06

AR--As received rock

C--Concentrate.

Table 15 - Typical Soil characteristics of various locations under the agronomical trials in India

Soil Characteristics	C.S.A.U.A.T. Kanpur	G.B. Pant Univ. of Agril. & Techn., Pantnagar	O.U.A.T. Bhubaneswar
1. Classification	Typic- Ustrochept	Mollisol	Inceptisol
2. Texture	Sandy- loam	Silty- Clay-Loam	Clay- loam
3. pH	7.85	7.4	6.2
4. P status	Low	Medium	Low
5. P Saptian Capacity	Low	Medium	High

Table 16 - AVERAGE YIELD DATA OF THREE REPLICATIONS AND THREE DOSES OF P<sub>2</sub>O<sub>5</sub> OF THE AGRONOMICAL TRIAL AT ORISSA UNIVERSITY OF AGRIL. AND TECHNOLOGY, BHUBANESHWAR.

Soil characteristics	Phosphate treatments	Mean yields (Kg./ha)		R.A.E.
		Kharrif'84	Rabi 1984-85	
		Direct: Test Crop: Paddy	Residual: Test crop: Green Gram (Phaseolus aureus)	
	1. Check	3183	795	
	2. T.S.P.	3831	920	102%
1. Soil Texture-clay-loam	3. 40% H <sub>2</sub> SO <sub>4</sub> PAPR (AR)	3922	949	102%
2. Soil classification- Inceptisol	4. 50% H <sub>3</sub> PO <sub>4</sub> PAPR (AR)	3990	921	103%
3. pH - 6.2	5. 25% H <sub>3</sub> PO <sub>4</sub> PAPR (AR)	3742	931	98%
4. Av. P <sub>2</sub> O <sub>5</sub>	6. 50% H <sub>2</sub> SO <sub>4</sub> PAPR (C)	3881	934	101%
5. P - sorption capacity - High	7. 50% H <sub>3</sub> PO <sub>4</sub> PAPR (C)	3876	951	102%
6. Rate of Application 0, 40, 80, 120 kg P <sub>2</sub> O <sub>5</sub> /ha				



TABLE 17 - AVERAGE YIELD DATA OF THREE REPLICATIONS AND THREE DOSES OF P<sub>2</sub>O<sub>5</sub> OF THE AGRONOMICAL TRIAL AT C.S. AZAD UNIVERSITY OF AGRIL. AND TECHNOLOGY, KANPUR

Soil Characteristics	Phosphate treatments	Mean yields (Kg./ha)				
		Kharif '84		Rabi 1984-85		
		Direct: Test Crop: Paddy	Residual Test Crop: Wheat	RAE* %	Direct: Test crop: Wheat	RAE %
	1. Check	4330	2900	86.6	3775	88
1. Soil texture-Sandy-loam	2. T.S.P.	4997	3347	100	4274	100
2. Soil classification-Typic Ustrochept	3. M.P.R. (AR)	4610	3445	96.6	-	100
3. pH - 7.85	4. M.P.R. (C)	4699	3367	96.7	-	100
4. Olsen p-6.5 ppm	5. 40% H <sub>2</sub> SO <sub>4</sub> PAPR (AR)	5030	3223	98.9	4217	98.7
5. P - sorption capacity-low	6. 50% H <sub>3</sub> PO <sub>4</sub> PAPR (AR) **	4806	3307	97.2	3925	91.8
6. Rate of Application: 0, 30, 60, 90 Kg P <sub>2</sub> O <sub>5</sub> /ha	7. 25% H <sub>3</sub> PO <sub>4</sub> PAPR (AR)	4723	3362	96.9	-	
	8. 50% H <sub>2</sub> SO <sub>4</sub> PAPR (C)	4951	2502	101.3	4151	97.
	9. 50% H <sub>3</sub> PO <sub>4</sub> PAPR (C)	4992	3223	98.5	4285	100.
	10. 25% H <sub>3</sub> PO <sub>4</sub> PAPR (C)	4937	3186	97.4	-	

\* This is the cumulative of Kharif'84 and Rabi residue crop

\*\* RAE of Rabi crop only.

TABLE 18. AVERAGE YIELD DATA OF THREE REPLICATIONS AND TREE DOSES OF  $P_2O_5$  OF THE AGRONOMICAL TRIAL AT G.B. PANT UNIVERSITY OF AGRICULTURE & TECHNOLOGY, PANTNAGAR, U.P.

Soil characteristics	Phosphate treatments	Mean yields (kg/ha)				
		Kharif'84		RAE	Rabi 1984-85	RAE
		Direct:	Residual		Direct	
		Test Crop: Maize	Test crop: Wheat		Test crop: Wheat	
. Soil classification	1. Check	6044	4222	88.7	4209	97
. Soil texture: Silty-clay-loam	2. T.S.P.	7321	4248	100	4308	100
. pH - 7.4	3. 40% $H_2SO_4$ PAPR (AR)	6719	4696	98.7	4250	98.6
. Olsen P Medium	4. 50% $H_3PO_4$ PAPR (AR)	7148	4481	100.5	4485	104.
. P - sorption capacity-High	5. 25% $H_3PO_4$ PAPR (AR)	7171	4253	98.8	-	
	6. 50% $H_2SO_4$ PAPR (C)	6377	4207	91.5	4374	101.
	7. 50% $H_3PO_4$ PAPR (C)	6090	4462	91.2	-	
	8. 25% $H_3PO_4$ PAPR (C)	7469	4638	103.9	4458	103.

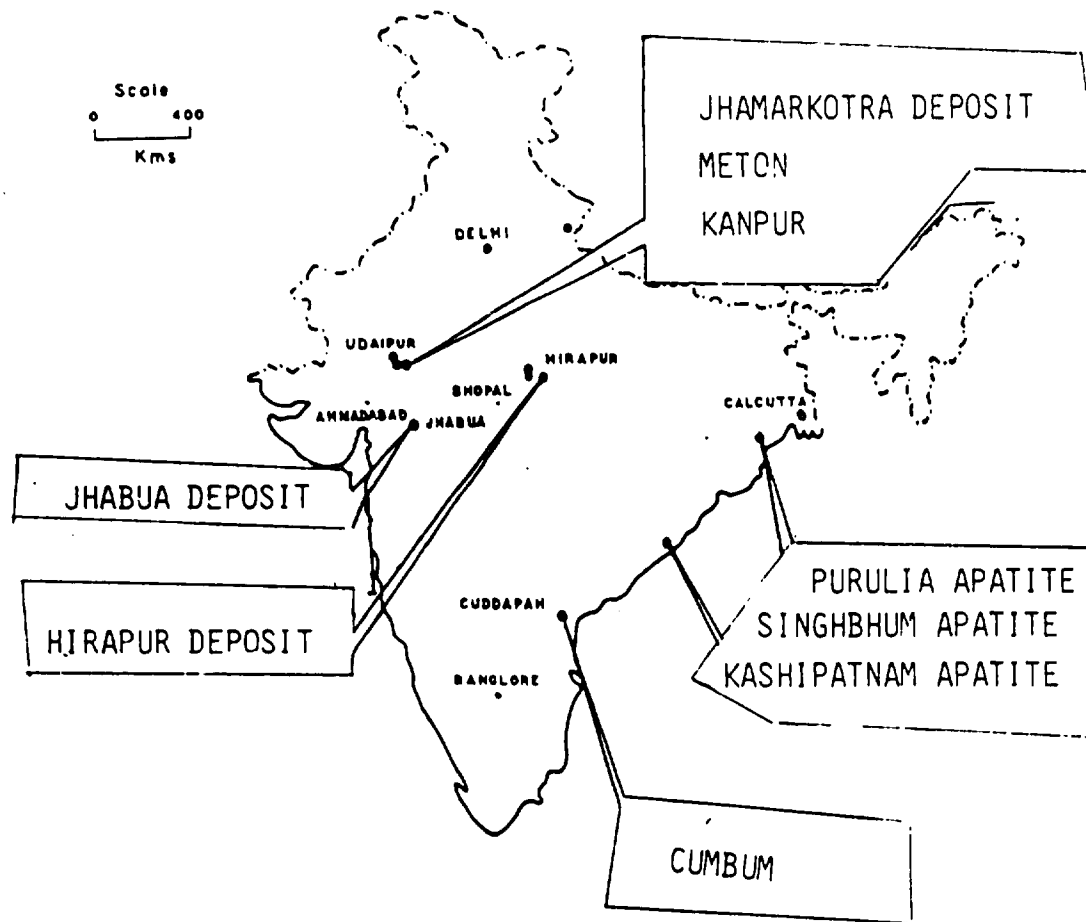


Figure 1—Apatite/phosphorite deposits in India.



Figure 2. Polished Rock Fragments. Black Areas Are Apatite; Lighter Gray Areas Are Carbonate.

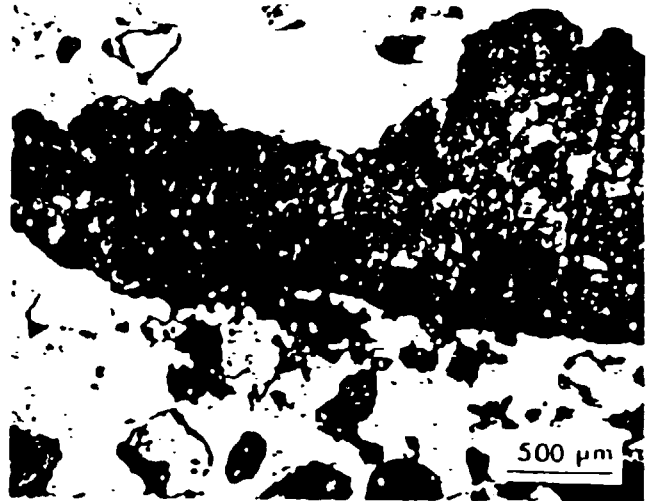


Figure 3. Plane Polarized Light View of Apatite Clasts (dark areas) in a Matrix of Calcite (light areas). Apatite Contains Small Quartz Inclusions.

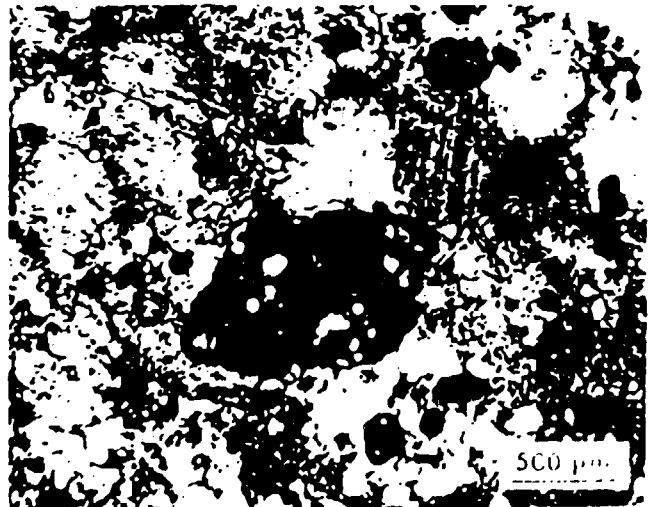
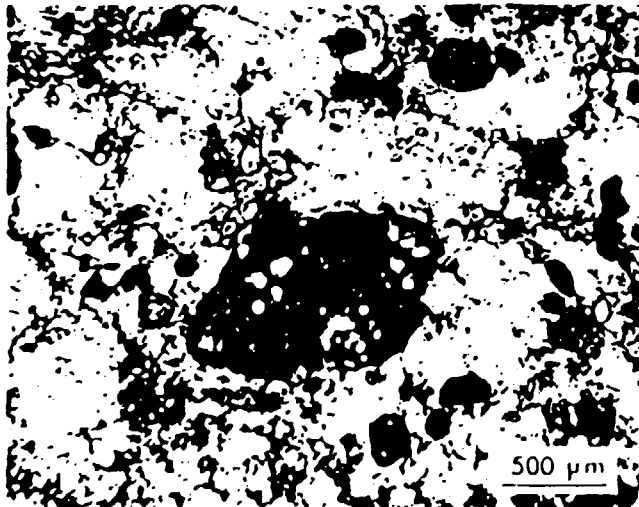


Figure 4. Plane Polarized Light View (left) of Apatite Pellets in Carbonate Matrix. In Crossed Polarized Light (right), Apatite Appears Isotropic (dark) With Birefringent Inclusions of Calcite and Quartz Endogangue. Carbonate Matrix Is Birefringent (white to gray).

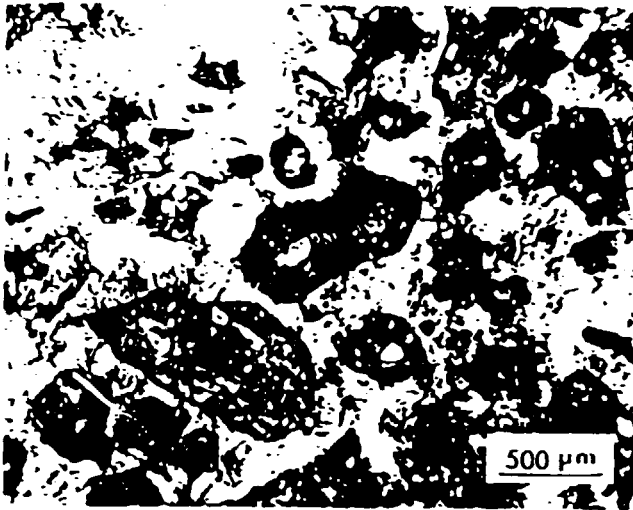


Figure 5. Plane Polarized Light View of Apatite Grains (dark) With Thin Overgrowths of Secondary Apatite. Matrix Is Calcite.

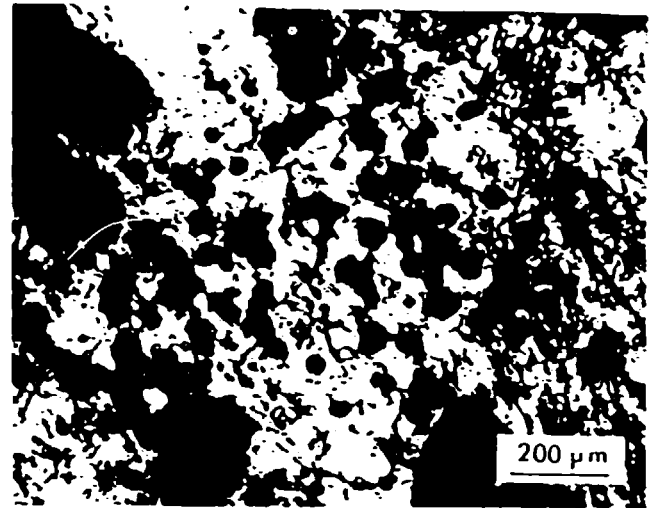


Figure 6. Plane Polarized Light View of Pyrite Grains (black, angular) and Apatite (larger, rounded dark grains) in Carbonate Matrix.

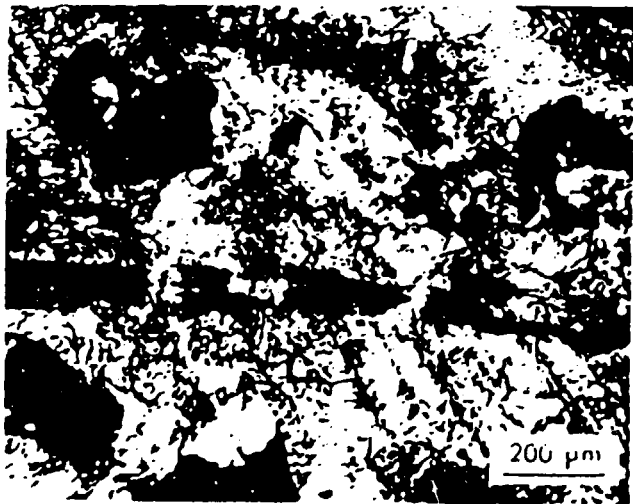


Figure 7. Plane Polarized Light View of Phosphatized Fossil Fragments (dark, angular) in Carbonate Matrix.

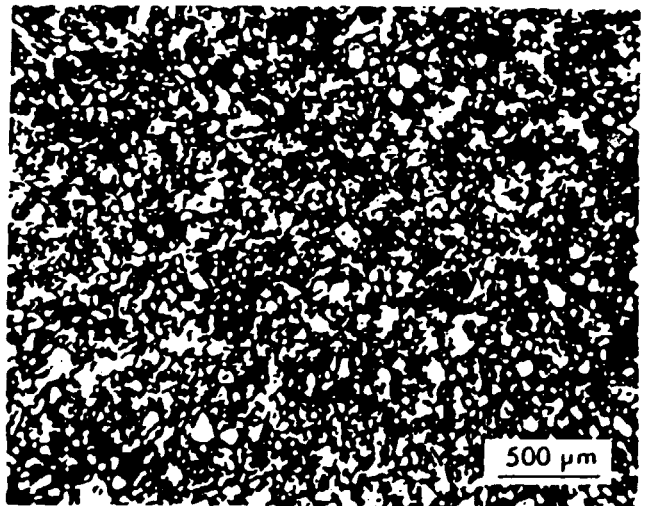


Figure 8. Plane Polarized Light View of Equigranular Intergrowth of Apatite, Carbonate, and Pyrite.

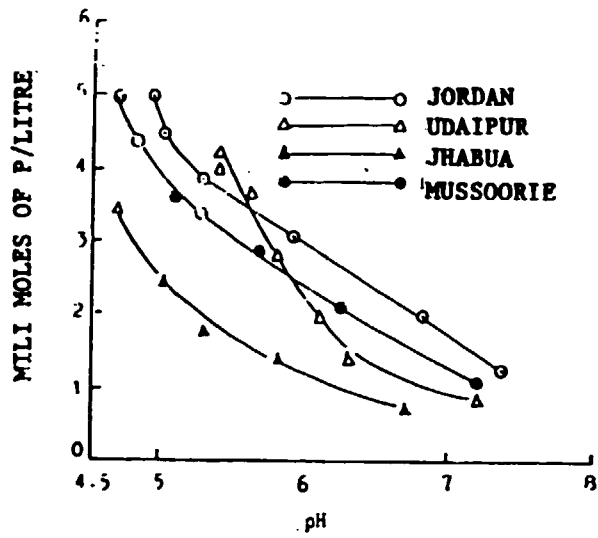


Figure 9 - P in solution after 24 hours.

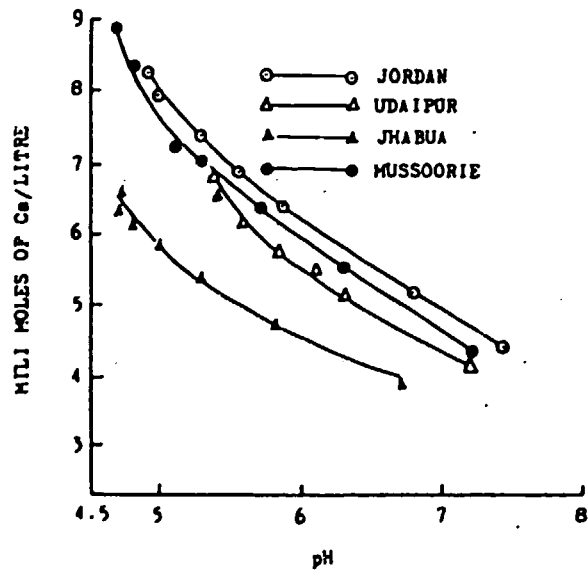
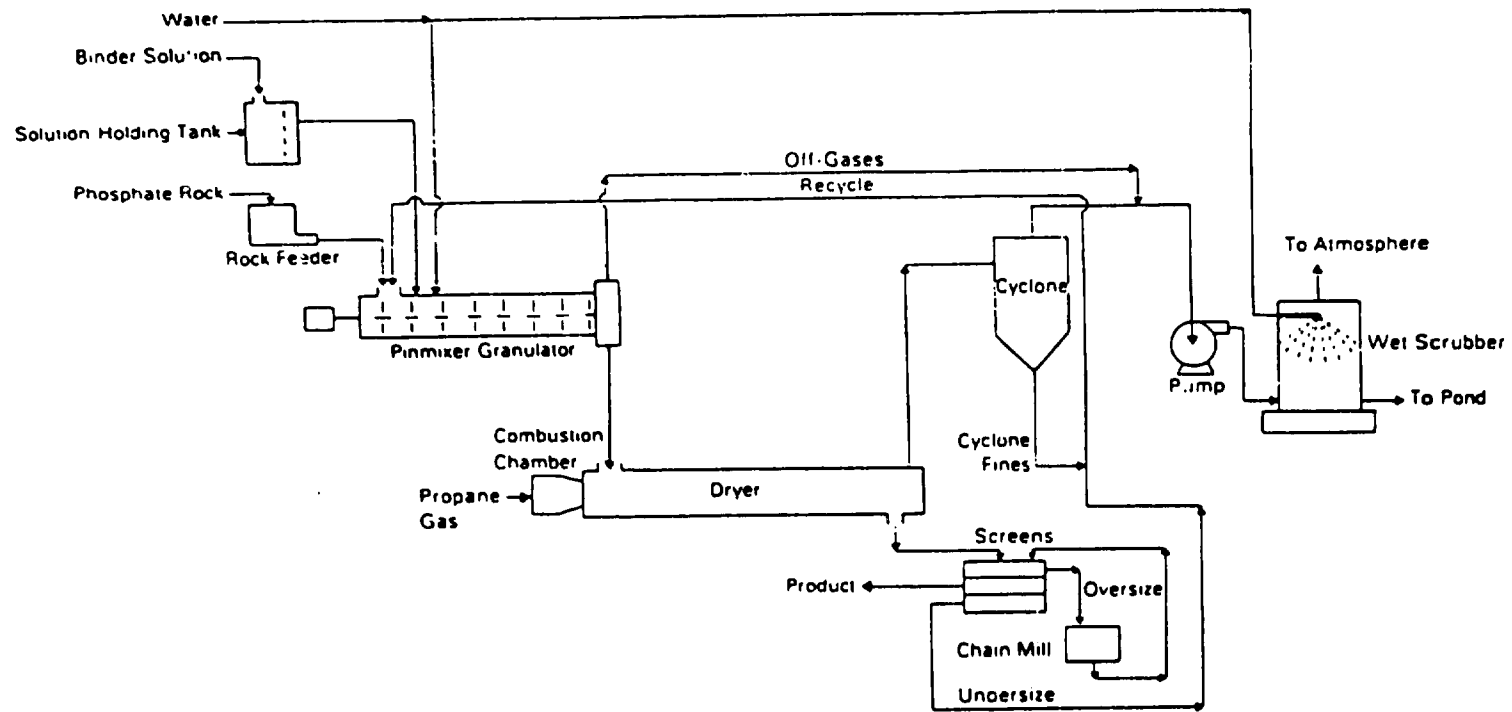


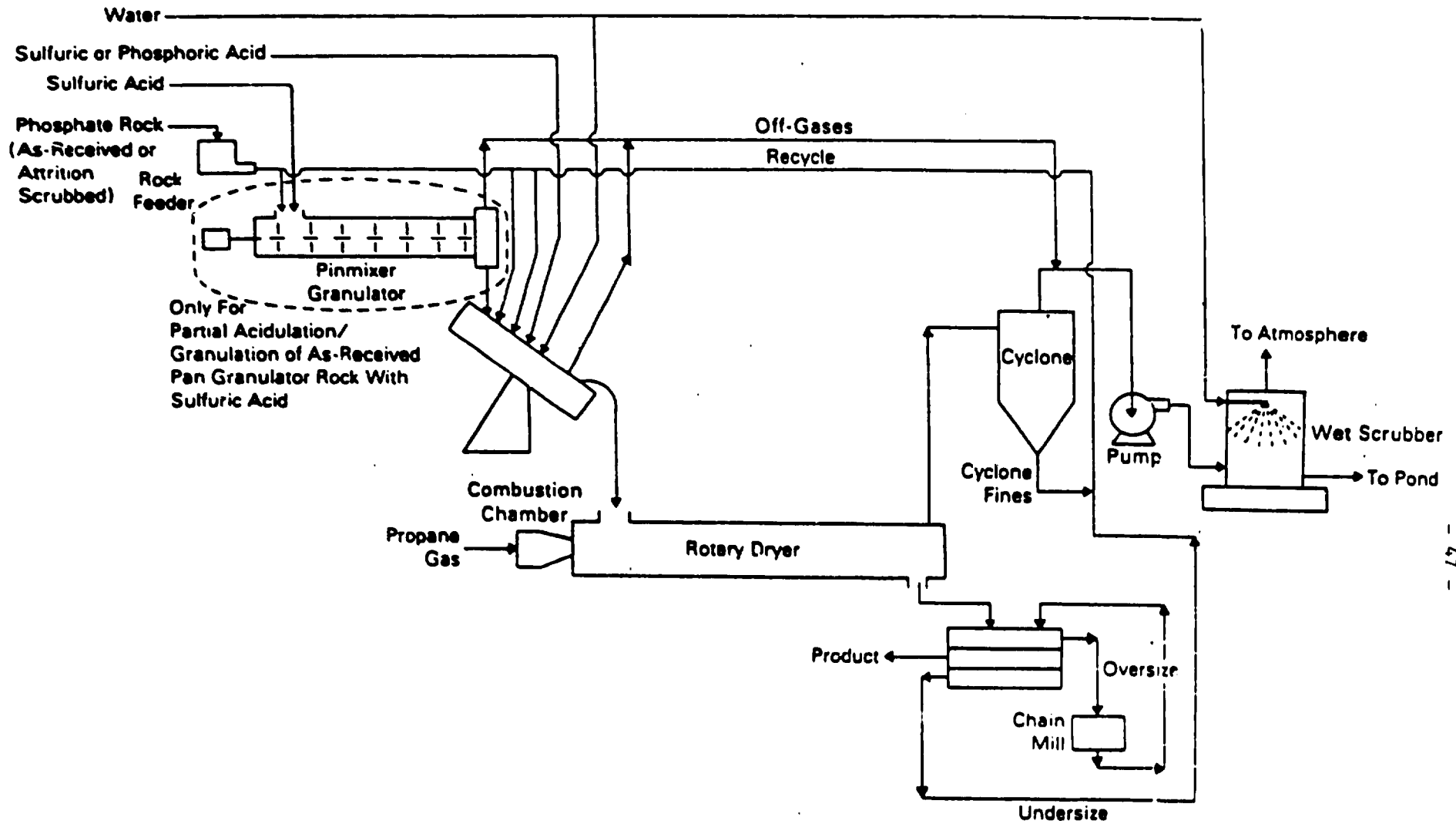
Figure 10 - Ca in solution after 24 hours

Figure 11.



IFDC Continuous Laboratory-Scale Process for Minigranulation of Phosphate Rock.

Figure 12.



Schematic Diagram of IFDC Laboratory-Scale Equipment Setup for Continuous Partial Acidulation/Granulation of Mussoorie Phosphate Rock.