5 ECONOMIC ASPECT OF THE MINERALS
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In order to ascertain the economic utility of the apatite-magnetite rock of Sung Valley (Sung block) in Meghalaya, the apatite and other usable minerals occurring in the deposit are to be considered. The minerals in the apatite-magnetite rock as such have not much importance, but their importance becomes manyfold when they are separated into 'apatite' and 'magnetite'. In the extraction process of 'apatite' from apatite-magnetite rock, 'magnetite' may be produced as by-product of the process. Moreover, rare-earth elements also might be tried to be extracted from the apatite fraction because rare-earth elements are concentrated in the apatite fraction. Nb, Ce and other rare elements concentrated in carbonatite as pyrochlore (may be Fe-Nb-rutile) may also be tried for extraction. It is just possible that the by-product minerals such as magnetite, rare-earth elements and rare elements like Nb, Ce, etc., will contribute towards partial compensation of the total cost of the apatite extraction process.
5.1 Calculation of Mean values of $P_2O_5$ and $Fe_{2}O_3$: To calculate total quantity of 'apatite' and 'magnetite' present in the Sung Valley (Sung block) deposit the mean values of $P_2O_5\%$ and $Fe_{2}O_3\%$ are to be evaluated. These mean values summarise all the grades of apatite-magnetite rock to a single grade. To calculate the mean values, the following two methods are to be adopted:

(1) Statistical method and
(2) Physical sample mixing method.

5.1.1 Statistical method: In this method, results of $P_2O_5\%$ and $Fe_{2}O_3\%$ of 769 numbers of different grades of apatite-magnetite core samples of different bore-holes were considered (Table 4.8).

To calculate the mean content of $P_2O_5$ and $Fe_{2}O_3$ (i.e. apatite and magnetite respectively) of the deposit, the following formulae (Goon, A.M. et al, 1983 p. 207) have been used: The formulae is

$$Y = \frac{\sum_{i=1}^{n} y_i}{n} \quad \text{and}$$

$$x = \frac{\sum_{i=1}^{n} x_i}{n} \quad \text{with usual expression.}$$

Where, $x$ stands for $P_2O_5$ and $y$ stands for $Fe_{2}O_3$, which are variables.

After computing the respective values in the above cited formulae the mean values of $P_2O_5\%$ and $Fe_{2}O_3\%$ were evaluated as:

$$P_2O_5\% = 9.3324 \quad \text{and}$$

$$Fe_{2}O_3\% = 22.3755$$
5.1.2 Physical sample mixing method: In this method, 150 numbers of different apatite-magnetite rock samples of different bore-holes were randomly selected. Approximately equal quantity of the samples were mixed. In this method, 10 different samples were prepared putting 128, 123, 114, 125, 127, 121, 126, 141, 150 and 150 respectively in each. The prepared samples were homogenised and analysed for the parameters and evaluated as:

\[ P_{2O_5} \% = 8.00 \]

\[ Fe_{2O_3} \% = 26.95 \]

Loss-on-Ignition \( \% = 15.55 \) and trace elements (Table 4.12). It is pertinent to mention here that the above cited values are average of prepared 10 average apatite-magnetite core samples.

The samples prepared as per above mentioned method were named as 'average samples' (AV). The values of the average samples may be considered as 'mean' values of the total apatite-magnetite rock deposit. The results of both the methods were found to be closer to each other.

In the physical sample mixing method, samples were mixed in approximate. Therefore, results of the statistical method appear to be more accurate. As such results of the statistical method were used for calculation. From the evaluated mean values, total deposit of apatite and magnetite were calculated (Table 5.1 Fig. 5.1a & 5.1b)

5.2 Beneficiation test of apatite and magnetite: In the laboratory method of beneficiation test, average samples were taken and magnetic fraction was separated with the help of bar-magnet and thin paper. The separated non-magnetic fraction was washed with distilled water to remove clay minerals and small adhering particles. The cleaned fraction was subjected to bromoform gravity separation followed by isodynamic magnetic separation. Finally apatite fraction was analysed for different parameters: \( P_{2O_5} \), \( Fe_{2O_3} \) and trace elements (etc.) (Table 4.2 & 4.19). The stepwise upgrade of the minerals may be shown in Fig. 5.2.
Table - 5.1

Total apatite, magnetite and other associated materials content in the total reserve of apatite-magnetite rock in Sung block of Sung Valley.

<table>
<thead>
<tr>
<th>Apatite content</th>
<th>Magnetite content</th>
<th>Others like -</th>
<th>Total (apatite + Calcite, Clay-magnetite) minerals etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>21.96</td>
<td>29.41</td>
<td>48.63</td>
<td>51.37</td>
</tr>
</tbody>
</table>

Parts of above constituents in Pie-diagram

| 79.06 | 105.88 | 175.07 | 184.93 |

In terms of $P_2O_5$, $Fe_2O_3$ and Phosphorous

<table>
<thead>
<tr>
<th>$P_2O_5$%</th>
<th>$Fe_2O_3$%</th>
<th>P%</th>
<th>$(P_2O_5+Fe_2O_3)$%</th>
<th>Others-Calcite, Clay minerals etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.3324</td>
<td>22.3755</td>
<td>4.07</td>
<td>31.71</td>
<td>68.29</td>
</tr>
</tbody>
</table>

Parts of above constituents in Pie-diagram

| 33.59 | 80.5518 | 14.65 | 114.16 | 245.84 |
Fig. 5.1a  Average proportion of the constituents of the representative apatite-magnetite rock of Sung Valley (Sung block).

Fig. 5.1b  Average proportion of the constituents of the separated apatite fraction from apatite-magnetite rock of Sung Valley (Sung block).
Fig. 5.2 Stepwise upgradation of minerals by laboratory method, of Sung Valley (Sung block) apatite-magnetite rock.
it has been noted that almost complete separation of apatite and magnetite is possible as there is no chemical bonding relation between them. Their only relationship is that they crystallized themselves in mutual contact from the same parent magma. However, grinding to their required grain size may play a major role in separation (for apatite inclusion may sometimes be present in magnetite skeleton, Plate 2.4). In view of the above, opening of the magnetite wall for taking out apatite inclusion, grain size study will help a lot for successful separation.

The separated non-magnetic fraction may be compared with the "Indian Bureau of Mines (1982) carried out Pilot-Plant-Scale beneficiation tests on 85 tonnes of rock phosphate samples (Block - 3) from Laffiper, U.P. for the U.P.-State Mineral Development Corporation Ltd. The sample assayed: 12.95% P₂O₅, 55.07% SiO₂, 4.15% Fe₂O₃, 4.73% Al₂O₃, 17.11% CaO, 0.40% MgO and 1.35% Loss-on-Ignition. Floatation with five-stage cleaning yield a concentrate assaying 35.54% P₂O₅, 7.93% SiO₂, 46.76% CaO, 0.15% MgO, 1.50% Fe₂O₃, 2.80% Al₂O₃ and 1.20% Loss-on-Ignition with a recovery of 68.20%. In spite of the low P₂O₅ content in the sample, a phosphate concentrate suitable for manufacturing of phosphatic fertilizers could be obtained with good recovery (IBM year book 1982)."

5.3 Magnetite and its analogues: The separated magnetic fraction (from apatite-magnetite rock) was assayed and was obtained the grade as given in the Table- 4.3. The minerals in the magnetic fraction are: magnetite, magnesioferrite, hollendite and coulsonite/etc..

The grade cited above for Sung Valley (Sung block) magnetite (Table - 4.3) is comparable with the "Indian Bureau of Mines" carried out pilot plant studies on upgradation of magnetite in tailings obtained from Jaduguda plant, Singhbhum district, Bihar for the Uranium Corporation of India Ltd. (UCIL). The tailing/reject at Jaduguda plant contains about 3% magnetite which the UCIL intend to upgrade to +95% magnetite. Pilot plant studies on 40 tonnes of magnetite concentrate revealed that a concentrate assaying 29.71% FeO corresponding to 95.67% magnetite could be produced with a recovery of 96.40% FeO. The concentrate may be suitable for use as medium in coal washeries." (IBM 1982).
Based on the IBM work on pilot plant, Bihar, it seems that Sung Valley (Sung block) magnetite is comparable and it has economic prospect. On the other hand, occurrence of magnetite (29.41% in average) in case of Sung Valley (Sung block) appears to be more encouraging over 3% magnetite of UCIL. Since higher the magnetite concentrate, better the beneficiation prospect, the Sung Valley (Sung block) apatite-magnetite rock may be definitely used for successful beneficiation of magnetite.

Regarding the total deposit of magnetite in Sung Valley (Sung block) it may be calculated as follows:

For the convenience of expression, let 'X' be the total amount of apatite-magnetite rock present in terms of million tonnes. From analysis, it was found that, 29.41% magnetite in average present in the deposit, i.e.,

100 gms of apatite-magnetite rock contains = 29.41 gms of magnetite (average)

or

100 million tonnes of apatite-magnetite = 29.41 million tonnes of magnetite-rock contains

1 million tonnes of apatite-magnetite = \( \frac{29.41}{100} \) million tonnes of magnetite

\( \text{or} \)

\( \text{or} \)

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Table - 5.2

Total apatite, magnetite and other associated materials content in the total reserve of apatite-magnetite rock in Sung block of Sung Valley, in terms of million tonnes, (Where 'X' is the total apatite-magnetite rock reserve in Sung block of Sung Valley)

<table>
<thead>
<tr>
<th>Apatite in million tonnes</th>
<th>Magnetite in million tonnes</th>
<th>Others-calcite, Clay, etc. in million tonnes</th>
<th>Total apatite+ Magnetite in million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2196 X</td>
<td>0.2941 X</td>
<td>0.4863 X</td>
<td>0.5137 X</td>
</tr>
</tbody>
</table>

Parts of above constituents in Pie-diagram

| 79.06 X | 105.88 X | 175.07 X | 184.93 X |

Above constituents in terms of Phosphorus, \( P_2O_5 \), \( Fe_2O_3 \), etc., in million tonnes.

<table>
<thead>
<tr>
<th>Total P</th>
<th>Total ( Fe_2O_3 )</th>
<th>Total ( P_2O_5 )</th>
<th>Others (Apatite + Magnetite)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0407 X</td>
<td>0.2237 X</td>
<td>0.0933 X</td>
<td>0.6829 X</td>
</tr>
</tbody>
</table>

Parts of above constituents in Pie-diagram

| 14.65 X | 80.53 X | 33.588 X | 245.84 X | 114.16 X |

N.B. :- 'X' may be obtained from Geological Survey of India.
Fig. 5.3 Average proportion of the constituents of the separated magnetic fraction from Sung Valley (Sung block) apatite-magnetite rock.
From the foregoing studies it can be inferred that the grade of Sung Valley magnetite (Table-4.3) is almost similar in grade to the beneficiated magnetite of Indian Bureau of Mines for UCIL. Since MU recommended the use of beneficiated magnetite as a medium of coal washeries, the magnetite of Sung Valley may also be used for similar purpose.

5.4 Apatite and its analogues: The apatite fraction with its separated from the apatite-magnetite rock of Sung Valley was assayed and the grade obtained has been shown in the Table-4.4. The minerals in the fraction are:

<table>
<thead>
<tr>
<th>Major minerals</th>
<th>Minor minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium hydroxide orthophosphate</td>
<td>Hydroxylapatite, Ca$_5$(PO$_4$)$_3$OH</td>
</tr>
<tr>
<td>Carbonate-apatite, Fluorapatite, Chlorapatite, strontiumapatite, bridgmanite (abukumelite), Fermorite, Thormire, Calcite/etc.</td>
<td></td>
</tr>
</tbody>
</table>

The expected reserve of apatite in Sung Valley may be calculated as follows:

For convenience of expression, let 'X' be the total amount of apatite-magnetite rock present in the reserve of Sung Valley in terms of million tonnes. From the analysis it has been seen that 21.96% apatite (in average) is present in the reserve i.e.,

100 gms of apatite-magnetite = 21.96 gms of apatite (in average) contains.

or

100 million tonnes of apatite-magnetite = 21.96 million tonnes of rock contains

1 million tonne of apatite-magnetite = \( \frac{21.96}{100} \) million tonnes of apatite rock contains

'X' million tonnes of apatite-magnetite = \( \frac{21.96 \times X}{100} \) rock contains
From the above calculation it is seen that about 0.2186 'X' million tonnes of apatite may be present in the Sung Valley (Sung block) apatite-magnetite reserve. This may, also be expressed in terms of phosphorus as 0.0407 'X' million tonnes. Both the expressions for apatite and phosphorus have been shown in the pie-diagrams respectively (Fig. 5.4a and Fig. 5.4b & 5.4c).

Like the phosphorite of Mussoorie area the Sung Valley (Sung block) apatite cannot be directly used as a direct fertilizer to the growth of plant or crops (PPCL/Jan. 1982). The reason of unsuitability to use directly to the plant as fertilizer is its high stability and low reactivity. Besides, calcium hydroxide orthophosphate $\text{Ca}_5 \left(\text{PO}_4\right)_3 \text{(OH)}$ is a highly stable compound and it does not break down easily in soil to release available phosphorus.

"Modern concept of the reactivity of phosphatic rocks for direct application takes into consideration of the isomorphous substitution in the fluorapatite crystal structure. Pure forms of unsubstituted fluorapatites rarely occur in nature except in phosphatic rocks of igneous origin.

The substitution which confers reactivity on phosphatic rocks is that of phosphate ion $\left(\text{PO}_4\right)^{3-}$ in the apatite crystal structure by carbonate ion $\left(\text{CO}_3\right)^{2-}$. Such a substitution brings about a deficit of one negative charge and one oxygen site on the lattice (ultimate unit in crystal structure) as has been illustrated (Fig. 5.5). To compensate for the deficit of negative charge, coupled substitution takes place somewhere else in the lattice, with ions of lower positive charge for replacing the ions of higher positive charge. In sedimentary apatites formed in marine environments, e.g., Mussoorie phosphorite, $\text{Ca}^{2+}$ ion (two positive charges) is replaced by $\text{Na}^{+1}$ ion (one positive charge) and $\text{Mg}^{2+}$ enters the lattice along with $\text{Na}^{+1}$, although it has no role in the balancing of the charge deficit.

Marine environment is rich both in sodium and magnesium ions. Therefore, substitution of each $\left(\text{PO}_4\right)^{3-}$ ion (which has four oxygen atoms and three negative charges) by one $\left(\text{CO}_3\right)^{2-}$ ion (which has three oxygen atoms and two negative charges) creates the crystal lattice due to a deficit.
Fig. 5.4a Total proportions in terms of apatite, magnetite and other associated materials in the total reserve of Sung Valley (Sung block) apatite-magnetite rock.

Fig. 5.4b Total proportions in terms of $P_2O_5$, $Fe_2O_3$ and other associated materials in the total reserve of Sung Valley (Sung block) apatite-magnetite rock.

Fig. 5.4c Total proportions in terms of Phosphorus, $Fe_2O_3$ and other associated materials in the total reserve of Sung Valley (Sung block) apatite-magnetite rock.
1. **SUBSTITUTION**

\[ \text{PO}_4 \] \rightarrow \text{CO}_3 \]

Oxygen Site—ON
Negative charge—0

2. **COMPENSATION**

- Deficit Oxygen Site
- Fluorine On Oxygen Site
- Deficit Negative Charge
- Loss of Positive charge

\[ \text{Ca}^{2+} \text{ substituted by Na}^{1-} \]

\[ \text{Mg}^{2+} \text{ accompanies Na}^{1+} \text{ but has no role in charge equalisation} \]

*Fig. 5.5 The process of isomorphous substitution of apatite crystal lattice.*
site of oxygen and deficit of one negative charge. Compensation of additional substitution elsewhere in the lattice takes place when

(i) $F^{-1}$ occupies the vacant site of oxygen, and
(ii) $Na^+$ ion (with one positive charge) substitutes $Ca^{+2}$ ion (with two positive charge) on the crystal lattice to neutralize the deficit of negative charge. The coupled substitution of $Mg^{+2}$ has no role but accompanies $Na^{+1}$ because of marine origin.

In brief, phosphate rocks of value (as direct application for fertilizer) have unique apatite crystal structure in which carbonate and fluorine substitute for phosphorus, sodium and magnesium substitute for calcium. In nature, however, there never exist ion to ion full replacement except partial one and the degree of substitution $(PO_4)^{3-}$ ion has not been found to exceed 21 percent. This means that out of six $(PO_4)$ ions in the apatite structure, the maximum that can be substituted by carbonate are about 1.26 on mole/formulae weight basis. Further, substitution leads to complete structure break down.

In francolite isomorphous substitution alters the chemical composition of fluorapatite $[3Ca_3(PO_4)_2CaF_2$ or $Ca_{10}(PO_4)_6F_2]$ in the same molar ratio as the degree of substitution of $(PO_4)^{3-}$ ion bears to the $(CO_3)^{2-}$ ion. Empirical formulae of the substituted apatite is written in the form shown below:

$$Ca_{10}(PO_4)_6F_2 \quad \text{Substitution} \quad Ca_{10-a-b}^{Na_{a}Mg_{b}}(PO_4)_{6-x}(CO_3)_{x}F_{y}F_{z}$$

(Fluorapatite) \quad \quad (Francolite)

Since it is coupled substitution $a$, $b$ and $x$ are inter related. Hence, if once value of $x$ is determined, the full empirical formulae of the substituted apatite can be derived.

A series of such substituted apatites are found in the natural phosphate rock which are called Carbonate-apatite or more commonly 'Francolite'. Only francolites are of value as phosphorus fertilizer for direct
application of certain physical characters inherited by them as a consequence of substitution. The noteworthy physical characters of Francolites are:

(1) Decrease in crystal size as measured through unit-cell parameters,
(2) Porous nature of aggregates,
(3) Increase in internal specific surface area and
(4) Development of structural incompatibility.

It is pertinent to mention here the characterization of Mussoorie-Phos for reactivity noticeable difference in ionic radii of the substituted and substituting ions (e.g., the ionic radius of Na$^+$ is about 5% smaller than that of Ca$^{2+}$), shrinkage in the unit-cell parameters of the crystal lattice structure of substituted francolites as compared to fluorapatite. Both the 'a' and 'c' dimensions of the apatite crystal structure are so affected. This is shown below:

<table>
<thead>
<tr>
<th>Unit-cell Dimensions (A(^0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a-axis) (A(^0))</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Highly substituted francolites</td>
</tr>
<tr>
<td>Zero substituted fluorapatite</td>
</tr>
</tbody>
</table>

Extensive research work done recently at IFDC (USA) and many subsequent correlation studies with a large number of phosphate rock samples have established that the variation in the a-axis of the unit-cell dimension of francolite is highly indicative and bears a very close relationship with their general empirical formulae. Thus, if the crystallographic a-axis can be determined through X-ray characterization technique, the degree of substitution or the CO\(_3\) : PO\(_4\) mole ratio of the apatite chemical composition can be readily found out. A high degree of correlation was obtained between the crystal chemical composition so determined and the
physical and chemical properties of the concerned francolite for use as phosphatic fertilizers for direct application. In practice, a-axis or the \( \text{CO}_3^{2-} : \text{PO}_4^{3-} \) ratio derived from it is recognised as the single value index of reactivity for rating phosphate rock for direct application. It was shown that higher the degree of substitution (a-axis value near to 9.323 Å), greater is the inherent rock reactivity as direct application as fertilizer (PPCL, 1982, P.12-15*).

The apatite in Sung Valley (Sung block) is soluble in acids. Therefore, it is resistant to alkali and neutral water. On the other hand, francolite formation of the apatite is also negligible. From all these points of view it cannot be directly used as a fertilizer for raising crops in cultivated fields. Even if it is used as direct fertilizer, the concentrated rare-earth elements will be lost. The valuable rare-earth elements may be extracted from the apatite fraction (EL-Kamar et al., 1979). The other use of the Sung Valley (Sung block) apatite may be for the manufacture of phosphatic fertilizer and/or phosphoric acid. The content of carbonateapatite and other forms of the apatite series do not hamper in the manufacturing process (Raha, 1970, Reedman, 1984). The rare-earth elements may be extracted from the same process, if possible.

In view of the above it can be said that the 'magnetite', 'apatite' and minor minerals of Sung Valley (Sung block) in Meghalaya has a bright economic prospect.

Based on the laboratory studies and established relation with the Indian Bureau of Mines carried out Pilot plant scale beneficiation test for rock phosphate, following process may be suggested for successful beneficiation of Sung Valley (Sung block) apatite-magnetite rock.

5.5 Prospect of Commercial beneficiation of apatite and magnetite: The apatite-magnetite rock of Sung Valley (Sung block) may be crushed and ground to the required mesh and the apatite-magnetite rock powder is allowed to go through the chamber containing water-flow, stirrer and magnetic field (Fig. 5.6). The water flow is along the path of the total...
Fig. 5.6 Flowsheet of the suggested wet process.
flow. The magnetic field is arranged perpendicular to the water and sample flow. Required grain size is necessary so that no apatite inclusion may remain in the magnetite. Water is used in the process to clean the clay minerals and washable particles from both apatite and magnetite. The stirrer used in the process was to help in cleaning.

The apatite-magnetite rock powder at the stirring chamber will stay at the floating stage. Simultaneously, magnetic particles (including magnetite) attracted by the magnetic field will be separated from the flow. As a result, non-magnetic fraction, including washable particles, will remain in the flow.

At the settling stage, non-magnetic heavier minerals including apatite and gangue materials settle down at this stage. At the same time, water washable light minerals and dust particles get separated themselves from the magnetite as well as from the heavier non-magnetic minerals because of the flow.

The settled down non-magnetic fraction usually contain apatite, its analogues and gangue materials. The recovered non-magnetic fraction, subjected in different stages of (cleaning floatation stages as required) process (Fig. 5.6) removes gangue materials like silicates etc.. The final products of the process are apatite, apatite-analogues, calcite, pyrochlore, etc.. In the entire process, the following products are obtained:

(a) Magnetite and its analogues,
(b) Apatite and its analogues, Calcite, Nb-carrier, Pyrochlore, etc.
(c) Washed fraction-clay minerals and smaller dust particles.
(d) By-product of the floatation stages, like silicates, etc.

The products at 'c' and 'd' above are of no interest but the products at 'a' and 'b' are of significant interest for the present study.