PETROLOGICAL STUDIES OF SOME PHOSPHORITE DEPOSITS OF HAZARA, PAKISTAN AND THEIR ECONOMIC IMPORTANCE

By

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ABSTRACT

Phosphorites occurring in Hazara are the only commercially workable deposits in Pakistan. These phosphorites are of sedimentary origin belonging to Cambrian age occurring in a number of localities in the area. The rock phosphate in Kabul area occurs in a folded and faulted sequence of Cambrian to Jurassic sediments. The geology of the area has been complicated by thrusts which have divided the phosphate bearing strata into a number of discrete thrust sheets. There are two phosphatic horizons in this area. The main occurrence is in the Abbottabad Formation where it is associated with chert and dolomite while, in Hazira it is associated with siltstone. Present studies are based on the phosphorite deposits of Kabul and Lambidogi belonging to Abbottabad Formation.

Field and laboratory studies reveal that these phosphorites were formed by the upwelling currents in the shelf environments. Later on when high energy conditions prevailed, this authigenically formed phosphate mud was reworked and pellets were formed. The associated dolomite is of secondary origin which probably was formed by the alteration of limestone, whereas chert was formed by incorporation of silica.

Hazara phosphorites are of good quality and the estimated reserves are about 20 million tons which are sufficient to fulfill the requirements of phosphatic fertilizers in Pakistan. Despite known large resources of phosphorite in Hazara, its annual production is about 40,000 tons. Selective mining of rock phosphate is being done at Kabul thus leaving huge quantities of low grade ore as dump. There is a need to undertake beneficiation and direct application studies for utilizing rock phosphate resources of the country more judiciously. Further, these
deposits should be exploited at a faster pace and efforts should also be made to explore the new ones in this district. Encouraging results in these directions can be obtained when the provincial and federal governments provide or facilitate the necessary technical and financial inputs to this phosphorite project, as has been done in case of Saindak polymetallic project in Baluchistan.
Chapter 1 INTRODUCTION
Chapter 1 INTRODUCTION

Hazara sedimentary phosphorites are the only commercially workable phosphate deposits in Pakistan, occurring at latitude 34° 30' N and longitude 73° 30' E. These deposits extend about 30 kilometers from Khota Qabar to Dalola areas in the vicinity of Abbottabad city in Hazara division of North West Frontier Province. The rocks exposed in the area range from Precambrian to Recent and have been mapped by Calcins and Matin (1968) and Latif (1970). The area is intensely folded and faulted and as a result the phosphate deposits are disrupted forming lenses and other smaller bodies.

Detailed exploration studies have been carried out by the Geological Survey of Pakistan (GSP) and Sarhad Development Authority (SDA) in collaboration with British Mining Consultants at Kakol, Lagarban, Tamawal, Kalad Bandi and northern Dalola areas. Total estimated reserves of these deposits are about 20 million tons (Hussain et al., 1993). SDA has been mining at Kakol since 1980 and the ore is being used in the manufacture of single super phosphate fertilizer at Haripur and Jarauwala plants.

Annual production of rock phosphate in Pakistan is about 40,000 tons which is far less as compared to its reserves. The rock phosphate production is not sufficient to meet our need of fertilizers and Pakistan imports huge quantities of rock phosphate as well as fertilizers from a number of countries. In order to curb the import we have to increase the indigenous production by exploring new deposits and utilizing the existing ones very efficiently.
1.1 SCOPE OF PRESENT STUDY

The present research work aims at:

1. Sedimentological Analysis.

No detailed sedimentological studies have been carried out so far. In the present studies lithological description of sedimentological units and facies description of the two sections, one at Kakul and the other at Lambidogi will be carried out.

2. Stratigraphic Summary

Many workers have contributed towards the stratigraphy of Hazara but the stratigraphy is not very clear and is confusing. The solution of this stratigraphic problem is out of the scope of the present work, but stratigraphic summary has been given for better understanding of the geology and genesis of Hazara phosphorites.

2. Petrography

There are many petrographic varieties of these phosphates, but there is a lack of detailed petrographic studies so a comprehensive classification of all these textural types is to be carried out.

4. Geochemical and Mineralogical Analysis

Detailed geochemical studies of Hazara phosphorites are also lacking. Major element chemistry will be carried out in this study. Hazara phosphorites have not been studied on the above mentioned lines, therefore, they remain least understood and unpublished as compared to rest of the phosphate deposits of the world.
5. Petrogenesis

These sedimentological, geochemical, mineralogical and petrographic data have been interpreted to give a model of genesis for Hazara phosphorites.

1.2 METHODOLOGY

The present work is a two phased study, Field and Laboratory. Field work has been carried out in order to study the sedimentological units in the study area and to collect the samples. These samples were used for making thin sections for petrographic studies and powder for geochemical analyses. A simple polarised microscope was used for thin section study. Powder samples were analysed on X-ray diffractometer and also by conventional gravimetric method.

1.3 PREVIOUS WORK

The history of research on Hazara area dates back to 1872 when Waagen and Wyma produced the first geologic map and established the stratigraphic relationships. The later studies were aimed at stratigraphy, structure and paleontology. The area lack sedimentological studies and thus the paleoenvironmental analysis. A brief summary of previous investigations is given below in chronological order.

Waagen and Wyma (1872) mapped Mount Sirban, situated to the south of Abbottabad and established stratigraphy of the area. Middlediins (1896) published a map on 1:126720 scale, incorporating unpublished data of Wyma. Wadia (1929) discovered glacial striations on
the Tumki boulders and confirmed an upper Carboniferous age, previously assigned by Middlemiss. Marks and Ali (1961, 1962) gave Jurassic age to the upper part. Latif (1963) assigned a Cretaceous age to the grey limestones, previously placed at the base of the Eocene by Middlemiss (1896) and confirmed the views expressed earlier by Wangen and Wynne. Davis and Gardņzi (1965) assigned the Jurassic age to the basal part of Triassic series on the basis of fossils. Callins and Matin (1968) prepared the geologic map of the Garhi Habibullah quadrangle on 1:63360 scale. They also mapped the area from Dalola to Kakul on 1:24000 scale. Hazara phosphorites were first discovered by Latif (1969) at Kakul-Mirpur area near Abbottabad. He described the stratigraphy of the area and discussed the age of the Abbottabad Group/Formation. He regarded the Abbottabad Formation or upper Carboniferous in age on the basis of the presence of Hyolithis in the shales of Hazara Member and the lithological correlation with Cambrian sections of the Salt Range and that of the Iran. Bhath et al. (1972) undertook a reconnaissance survey for the phosphate exploration in Guldenian, Laggarin, Dalola and Daband areas. They mapped the area at a scale of 1:12000 to locate the phosphate rock. They did some petrographic and mineralogic work and concluded that the phosphate was deposited in shallow water along a beach in oscillatory environments. Ghaemavi et al. (1978, 1980) carried out studies on geology, reserves and economics of these phosphate deposits.

In 1976 Sarhad Development Authority (SDA) in collaboration with British Mining Consultants did some exploratory work and started mining of phosphate rock at Kakul but their work remained unpublished. Since then SDA is engaged in mining and exploration of Laggarin, Tarnawai and other deposits in the area. In 1983 Ashraf and Malik worked on the
prospects and development of phosphate deposits of Lagarban area and also carried out some beneficiation studies. Field geological and mining data of Kakul phosphorite were carried out by Nazir (1989) and Khan and Ahmad (1991). Few petrographic, geochemical, mineralogical and economic studies on the Kakul phosphorite were carried out by Hasain et al. (1987, 1990, 1993).

1.4 Stratigraphy

The Geology of Hazara has remained an interesting problem for over a century and has attracted many geologists. Many of these workers contributed towards stratigraphy but still it is not very clear.

Wangen and Wyne (1872) named the lower sediments i.e. quartzitic, slates, silty shales, sandstones and siltstones interbedded with calcareous shale and limestones as Attock Shales. Wadia (1934) also called it as Attock Shale. While Marks and Ali (1961) recognized them as the Hazara Slate Formation. Latif (1974) upgraded the name as Hazara Group, and has subdivided it into four Formations (Table-1). Latif (1974) has subdivided the Abbottabad Group into two Formations:

1. Kakul Formation
2. Sirban Formation

Kakul Formation is again subdivided into four members. Sirban Formation was identified by Wangen and Wyne (1872). Latif (1974) has identified this unit as Formation because of its distinct lithological characteristics as compared to the overlying and underlying rocks, its enormous thickness, and wide lateral distribution in the area. Later workers like Bhatti and Hasan (1972), Ghaznavi and Karim (1978) (Table-2), Bhatti
Ghaznawi (1980) (Table-3) called it as the Abbottabad Formation. However, Ghaznawi and Karim have divided the Abbottabad Formation into two members the upper dolomite member and a basal quartzite sandstone and conglomerate member instead of Kakul and Sirban Formations. Their succession is given below:

**Table-1**

*Succession given by Latif (1974)*

<table>
<thead>
<tr>
<th>Group</th>
<th>Formation</th>
<th>Member</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thundian</td>
<td>Maira</td>
<td>Lower Jurassic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tarnawai</td>
<td>Hazira</td>
<td>Galdanian</td>
</tr>
<tr>
<td></td>
<td>Disconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sirban</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abbottabad</td>
<td>Mirpur</td>
<td>Cambrian</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kakul</td>
<td>Mahamdagali</td>
<td>Sangargali</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tawakki</td>
<td></td>
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<tr>
<td></td>
<td>Unconformity</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Tund</td>
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</tr>
<tr>
<td>Hazara</td>
<td>Upper</td>
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<tr>
<td></td>
<td>Langrial</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Limestone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Miranji</td>
<td></td>
<td>Limestone</td>
</tr>
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Table 2

Succession given by Ghaznavi and Karim (1978)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Major Lithology</th>
<th>Age</th>
</tr>
</thead>
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<tr>
<td>Daulatmar Limestone</td>
<td>Limestone</td>
<td>Jurassic</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Unconformity</td>
<td></td>
</tr>
<tr>
<td>Gallanian Formation</td>
<td>Shales, quartzite</td>
<td>Early</td>
</tr>
<tr>
<td></td>
<td>sandstone</td>
<td>Cambrian</td>
</tr>
<tr>
<td>Abbottabad Formation</td>
<td>Dolomite interbedded</td>
<td>Early</td>
</tr>
<tr>
<td></td>
<td>with this chert layers</td>
<td>Cambrian</td>
</tr>
<tr>
<td></td>
<td>Unconformity</td>
<td></td>
</tr>
<tr>
<td>Hazara Formation</td>
<td>Slates, phylites</td>
<td>Precambrian</td>
</tr>
<tr>
<td></td>
<td>and shales</td>
<td></td>
</tr>
</tbody>
</table>

There is a gradational contact between Gallanian and the underlying Abbottabad Formation and both the Formations contain phosphate. The upper contact of Gallanian Formation with Daulatmar Limestone is disconformable. These Limestones are the youngest rock type exposed in the area and their age is Jurassic.
Table 3

Succession proposed by Hasan and Ghaznavi (1980)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age</th>
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</thead>
<tbody>
<tr>
<td>Hazira</td>
<td>Lower Carboniferous</td>
</tr>
<tr>
<td>Abbottabad</td>
<td></td>
</tr>
<tr>
<td>Tanawal</td>
<td>Precambrian</td>
</tr>
<tr>
<td>Hazara</td>
<td>Precambrian</td>
</tr>
</tbody>
</table>

Latif suggested that the upper two formations namely the Gilgitian and Hazira may be grouped to be known as Tarnawal Group in any future regrouping. It seems that both the Hazira and The Gilgitian Formations do not fulfil the conditions for a formation so they may be down graded as member of Tarnawal Formation.

The succession given by Hasan and Ghaznavi is accepted by the Stratigraphic Committee of Pakistan. This is a simple succession but the division of Abbottabad Group of Latif into two Formations seems to be more reasonable because the Sirbot Dolomites occur in a wide area and everywhere its thickness is reasonable to call it a Formation as Latif named it a Formation. Work should also be done on Hazira and Gilgitian Formations as whether they fulfil the conditions for a Formation or not. After doing a detailed research on these stratigraphic units a single and acceptable stratigraphic succession should be adopted for further future work which will encourage future studies on environment of deposition and economics of these phosphorites.
Fig. 1. Index Map Showing Locations of Phosphate Occurrences (After Bhatti et al., 1972).
Chapter 2

GEOLOGY

2.1. GENERAL GEOLOGY AND STRUCTURE OF THE HAZARA AREA

The phosphorite bearing strata occurs on the western flank of Hazara-Kashmir synaxes which was initially defined by Wadia (1931). The study area and its surroundings have a complicated structure (Fig-2). Besides Hazara-Kashmir synaxes, three main regional structural features of this area are: 1) Punyal or Tarnawai Fault, 2) Murree or Jehlum boundary fault and 3) Garhi Habibullah syncline (Fig-3). These boundary faults have caused differential movement in the region and many complex folds and faults have been developed. In addition to these three faults there are three smaller strike-slip faults, one in south east and two in the west. These faults have cut and obliterated the tight folds. The highly complicated nature of the structure has adversely affected the strata and that the phosphate deposits are disrupted into smaller bodies.

There are various rock units exposed in the area i.e. phosphorite, dolomites, chert, siltstone, quartzite, shale, sandstone, red beds and limestone ranging in age from Precambrian to Jurassic. Present study is focused on the phosphorites of Kadool and Lambodari areas, therefore, these phosphorites and associated rocks are discussed in detail.

2.2 FACIES DESCRIPTION:

On the basis of lithology, following main lithofacies can be identified in the study area.
1. Phosphorite
2. Dolomite
3. Chert

1. PHOSPHORITE:

Phosphorite occurs from Khota-Qabar to Dalola near Garhi Habibullah striking north-east. Phosphate occurs in two horizons:

a. Lower Horizon:

Most of the phosphate deposits occur in the lower phosphatic horizon. It is exposed at Kalul, Lagarban, Lambidogi Kaledibandi, Sirban, Tarsawai and Sabanguli where phosphorite is associated with cherty dolomite unit of the Sirban Formation.

b. Upper Horizon:

The upper phosphatic horizon occurs in association with hematite siltstone of the Hazira and Galdanian member of the Tarsawai Formation (Latif 1974) and is exposed at Dalola and Sirban areas.

The study area is Kalul and Lambidogi, so these phosphorites will be discussed in detail.

Rocks at Kalul mine section strike North East and dip 55° North West. Sirban dolomite which is exposed at this section is about 1660 meters thick but only the uppermost 167 meter is exposed along mine-ridge (Khan and Ahmad, 1991). (Fig.4). These dolomites are interbedded
with few to 12 cm thick grey layers of chert. These cherts are white on weathered surface and grey on fresh surface. Upward in the sequence these dolomite beds gain thickness up to 2 meters. The interbedded chert is sometimes nodular. The dolomites are generally laminated but sometimes the individual beds are not identifiable. These cherty dolomites grade upwards into banded chert with about one meter thickness. Overlying the chert is about 1.7m thick limestone layer. Conformably overlying it is 8 meters thick dolomite layer which is interbedded with chert layers. Above it is 50-60 meters covered strata. Conformably overlying it is 2 meters thick phosphorite which is thin to medium banded, peloidal and is dark grey to black in colour. When observed carefully these phosphorites show papery laminations and have wavy top. Above it is again siliceous phosphate layers. This phosphate has again conformable contact with overlying cherty shale. These are dark olive coloured planar bedded siltstone which are about 2.5 meters thick. Above it, is brecciated, cherty olive green siltstone which has indistinct bedding. Then a conglomerate layer on which lies arenaceous limestone of Jurassic age belonging to the Samana Suk Formation. Strata is repeated many times, in this area because of intense folding.

Lambidogi deposit is 9.5 km from Abbottabad city. These deposits are located north of Kādal phosphate mine. At Lambidogi 17 m thick reworked cherty dolomite is at the base and above it is one meter thick phosphorite (Fig-5). Conformably overlying it is again 2 meters thick dolomite which passes into 2 meters thick dolomitic phosphate which in turn passes into a 7 m thick sandy dolomite horizon.
2. DOLOMITE

In Sirban Formation, the quartzites grade upward through a zone of thinly bedded dolomitic siltstone and silty dolomite. Dolomite is mostly massive but also laminar varieties are present. At Kabul the dolomite is of sucrosic texture which may be due to loose fitting of dolomite rhombohedra. At Lambidagi, dolomite is interbedded with massive phosphorite. Chert is interbedded with dolomite in both the localities.

3. CHERT

This facies found in the Sirban Formation, at Kabul, underlies the main phosphorite zone and varies in thickness up to 13 meters. Due to tectonic disturbances the chert is brecciated and these sheared zones show iron leaching. At places there is a complete gradation from phosphatic chert through cherty pelleted phosphorite into the main phosphorite zone. Much of the chert of the lower portion resembles the banded chert of the underlying dolomites, but the upper part contains thin beds of siltstone. The presence of phosphate in the inter-bedded chert indicates anoxic conditions.
Fig 3- Tectonic Map of Southern Hazara District and part of Western Kashmir
Fig. 4: Measured Stratigraphic Section of Abbottabad & Galdanian Formations exposed near Kekul Abbottabad.
FIG. 5: Measured section of Sirban Formation exposed at Lambidogi, Abbottabad.
Chapter 3

PETROGRAPHY AND GEOCHEMISTRY
CHAPTER 3
PETROGRAPHY AND GEOCHEMISTRY

3.1 INTRODUCTION

The understanding about world phosphorite has increased tremendously over the past two decades, particularly with respect to the sources of phosphorus for these deposits, the interpretation of their unique sedimentology, their paleoceanographic and paleogeographic settings (Glenn et al., 1994).

The wide range of textures, different particles and processes of formation have made it difficult to give a simple classification of phosphorites. Riggins (1979a) applied a modified genetic (Folk, 1962) carbonate classification to phosphorites as orthochemical and allochemical types. Cook and Shergold (1986) gave a classification based upon the Dunham (1962) textural carbonate classification—wackestone, packstone, grainstone and boundstone phosphorites. According to Glenn et al. (1994), the Dunham scheme has better applicability in the field and the Folk's (1962) classification has advantages in microscopic studies.

Slansky (1986) proposed a classification which combines elements from both Folk (1962) and Gubanov (1984) and called
Sixty samples out of 100 rock samples were selected for preparation of thin sections from various horizons of the Abbottabad Group, Sirban and Kakul Formations.

3.2: PETROGRAPHY OF PHOSPHORITE

The main phosphate bearing mineral is apatite. Phosphate (apatite) is found in many different textural types. A classification of Hazara phosphorite is proposed (Table-4) which is modified after Folk (1959), Riggs (1979 a,b), Prevot (1981) and Slansky (1986).
### Petrographic Classification of Hazara Phosphorites

<table>
<thead>
<tr>
<th>A</th>
<th>Phosphate Containing Less Than 20% Phosphate Grains</th>
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<tr>
<td>A: Dolomitic Phosphate</td>
<td></td>
</tr>
<tr>
<td>1) Peloidal phosphate</td>
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<td>2) Clastic phosphate</td>
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<table>
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<tr>
<th>B</th>
<th>Phosphate Containing More Than 20% Phosphate Grains</th>
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<td>A: Type of Groundmass</td>
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<td>1) Dolomitic</td>
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</tr>
<tr>
<td>2) Cherty</td>
<td></td>
</tr>
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<td>3) Phosphatic</td>
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</tr>
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<td>4) Mixture of all three</td>
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<table>
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<th>B: Siliceous Phosphate</th>
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<td>1) Cherty groundmass</td>
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<td>2) Silstone groundmass</td>
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<table>
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<th>B: Type of Pellets</th>
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<td>1) Peloidal</td>
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<tr>
<td>2) Peloids</td>
</tr>
<tr>
<td>3) Clastic</td>
</tr>
</tbody>
</table>
A. PHOSPHORITE CONTAINING LESS THAN 20%

PHOSPHATE GRAINS:

This is classified into two sub-types:

1. Dolomite Phosphate

The groundmass of dolomite phosphate contain less than 20% of phosphate grains. These phosphate grains range in size from .005-.02 mm. Very few oolithic grains are present and all the phosphate grains are of two types:

a. Peloidal grains:

Rounded to subrounded grains of phosphate with well intact grain boundaries. These grains contain inclusions of fine dolomite grains and occasionally of siliceous particles. Dolomite rhombs are also noted occurring as inclusions within the phosphate grains and also in the matrix.
b. Clastic grains:

Irregularly shaped grains of phosphate occur in the matrix of dolomite. These phosphate grains have irregular and fractured grain boundaries (Fig-6).

2. Siliceous Phosphate.

In the siliceous phosphate the matrix is fine grained siliceous matter, which contain pellets of phosphate. It can be divided further into two types.

i) When siltstone is in the groundmass:

Size of silt is about .001-.005 mm and clasts of phosphate of about .004-.05 mm size are present in the groundmass.

ii) When chert is present as the groundmass.

The size of phosphate grain is larger than that of occurring in the siltstone and varies between .01-.05 mm. Sometimes these two types (i & ii) may occur in the same slide (Fig-7).
Fig. 6. Phosphate grains with fractured grain boundaries in the Dolomitic mosaic. Cross nicols x 40

Fig. 7. Cherty and Dolomitic groundmass both in contact with each other (both contain phosphate grains). Plane x 100.
B. PHOSPHORITE CONTAINING MORE THAN 20 %

PHOSPHATE GRAINS:

The phosphate occurs as grains or pellets called allochens or allochemical grains (Riggs, 1979 a). There are two further subdivisions of this type:

1) Division based upon the groundmass material and
2) Division based upon the texture of the pellets (or phosphate grains).

1) Division based upon the groundmass material:

On the basis of type of groundmass this category can be broadly divided into four sub types:

i) Where the groundmass is microcrystalline dolomite.

Dolomite occurs as rhombic grains in the groundmass (Fig-8). These dolomite grains show high interference colors. The phosphate grains occurring in this dolomitic groundmass are classic. They vary in size from 0.5 mm to 1 mm or even more and
Fig. 8. Dolomite grains and rhombs (D) and opaque ore in Phosphate groundmass. Cross nicols x 40.
have irregular shape with irregular grain boundaries. Very small crystals of hematite occur along the margins of some of these phosphate pellets/grains.

ii) Where groundmass is microcrystalline silica

Chert occurring in the groundmass is very fine grained. Patches of dolomite are also present in the groundmass besides the phosphate grains/pellets. The phosphate grains present here are of three types, i.e. pseudo-solitic, peloidal and clastic. The clastic grains are irregular in shape and have irregular grain boundaries. Peloidal and pseudo-solitic grains are rounded to subrounded in shape (Fig.9.a,b). All these grains contain inclusions of small quartz grains. Sometimes two or three grains of phosphate are found encased in a single aureole (Fig.10.a,b). Fine grained iron oxide occurs scattered in the rock.

iii) Where groundmass is microcrystalline phosphate.

Microcrystalline apatite occurs in the groundmass and is called orthochemical phosphate (Riggs 1979a).
Fig. 9.b. Pseudo-oolites of phosphate in the chert groundmass. Plane x 40.

Cross nicols x 40
Fig. 10.a. Two grains of Phosphate encased in a single aureole.
Plane x 100.

Fig. 10.b. Three grains of Phosphate encased in a single aureole.
Plane x 100.
Pseudo-ooliths and clastic grains of apatite are present in the groundmass (Fig-9). In some thin sections clastic grains are aligned in some preferred direction which may show stresses. Very few grains of iron oxide are scattered in the rock.

In some thin sections microsparophite is found in sharp contact with phosphatic chert. At some places cherty veins cut across the microsparophite or AVades microsparophite. Pellets are the most common allochems of these phosphorites which include pseudo-ooliths, peloids and clasts. Pellets are found embedded in the microsparophites (Fig-11). These pellets vary in shape from rounded to subrounded and oval and, range in size from a fraction of one mm to one mm or even more. Most of the pellets show recrystallized apatite, silica and carbonates at the grain boundary. Pellets occur both as individual grains and also as aggregate grains with adjacent grain boundaries (Fig-12).

v) Where groundmass is a mixture of cryptograined chert, carbonates, microsparophite and iron oxide.

Some pellets are very large in size (upto 1 mm) and are peloidal in shape. Thick bands of recrystallized silica, carbonates and apatite are quite common along the margins of the pellets (Fig-13). Some grains are of dark color because of replacement of phosphate by iron oxide.
Fig. 11. Phosphate grains embedded in microspherite groundmass.
Plane x 40.

Fig. 12. Recrystallized grain boundaries of apatite pellets.
Plane x 40.
Division based upon the texture of the phosphate pellets

1) Pseudo-solitic

Rounded or sub rounded grains with internal ringed type structures. These rings occur around a center without a nucleus so these grains are not called oolites but may be named as pseudo-oolites (Fig-8).

b) Peloidal

Rounded to sub-rounded grains with well intact grain boundaries. These peloids contain inclusions of carbonates, silica and iron oxide. There is no internal structure seen in these peloids (Fig-13).

iii) Clastic

These grains are irregular in shape and have fractured grain boundaries (Fig-14). Many diagnostic features are observed in the Hazara phosphorites; recrystallized quartz, apatite and carbonates, recrystallized veinlets of carbonates and microstylolites.

\[ N:\ 25 \]
Fig. 13. Phosphate grains with well intact grain boundaries. Plane x 25.

Fig. 14. Phosphate grains with fractured grain boundaries. Plane x 40.
3.3. PETROGRAPHY OF DOLOMITE

Two types of textural classes are recognized in the dolomites:

i) Fine grained (.02 cm) and ii) Course grained (.5mm)(Fig-15).

Mostly the dolomites are fine grained and inequigranular. The grains are subhedral to subhedral presenting a crystalline sucrosic mosaic with interlocking grain boundaries (close packing) (Fig-16.a,b). Quartz silt present in these dolomites are generally larger in size than the dolomite crystals. Relict grains of calcite and small grains of black are occur at places in the rock.

In plane polarized light, patches of darker colour are seen in these fine (size varies from few microns to few tens of microns) dolomites which are due to the aggregates of course grain-dolomite (Fig-17). These patchy structures may be the ghost structures of some skeletal material, and would be more susceptible to dolomitization hence represents the change in the time of dolomitization from rest of the rocks. The course grains of dolomite show twinning at cleavage sets (Fig-15, a); rhombs and zoned structures(Fig-18).
Fig. 15. Mosaic of coarse and fine grained dolomite with opaque ore. Cross nicols x 40
Fig. 16.a Dolomite mosaic showing relict grains of calcite (C)
Cross nicole x 100

Fig. 16.b Dolomite mosaic showing rhombs.
Plane x 40
Fig. 17. Dark patches in Dolomite showing ghost structures of some skeletal material. Plane x 100

Fig. 18. Dolomite grains showing zoning. Cross nicols x 40
3.4 PETROGRAPHY OF CHERT

In thin section chert appears as a colourless, microcrystalline aggregate, mostly composed of fine quartz crystals with variable quantities of finely disseminated impurities (calcite, albite, feldspar, iron ore etc.), here-in referred to as groundmass.

There are two main types of silica grains found in these cherts:

1) Microcrystalline silica.

2) Zebratic chalcedony and spherulitic quartz

The microcrystalline quartz (σ) occurs in bands or laminae. The most striking variety of fibrous micro quartz is zebratic chalcedony which forms a common cavity lining (McBride, 1979). Microspherulites are present which cause laminae and mostly the zebratic chalcedony is developed along these microspherulites (Fig 19). The second variety of silicas in these cherts is spherulitic quartz (Fig 20.a,b). There is a mass of tangled thread-like substance which is also cavity lining (Fig 21) (Folk and McBride, 1976).
Fig. 19. Zebraic chaledony developed along the stylolites in chert.
Cross nicols x 40
Fig. 20.a Spherulitic quartz in chert. Cross nicoles x 40

Fig. 20.b Spherulitic quartz in chert. Cross nicoles x 100
Fig. 21 Tangled thread like substance in chart. Plane x 40
3.5. INTERPRETATION OF PETROGRAPHIC STUDIES

The occurrence of both arbochemical and allochemical phosphorites in this area indicates that originally the arbochemical phosphate was deposited biochemically in low energy conditions. Later, when locally high energy conditions prevailed, reworking of this authigenic microcrystalline phosphorite mud took place and pellets and pseudo-oolites were formed (Riggs, 1979a). Thus the microphosphorite forms the source for pelletal phosphate in the Hazara phosphorites.

The oriented grains, presence of stylolithes in phosphorites and the deformed and fractured grains shows that intense deformation has taken place in the area.

The presence of relic calcite grains in dolomite samples show that this dolomite is secondary in origin, formed by the replacement of early formed calcium carbonate. The presence of stylolithes shows diagenesis. Quartz grains in the dolomite are of the primary origin which further confirm that the dolomites are of secondary origin. Zoning in the dolomite rhombohedra show the presence of iron. Patchy structure in these dolomites show that these dolomites were formed in more than one phase of alteration (Mathes and Mountjoy, 1980). In chart the presence of ghosts of euhedral rhombo dolomite grains, suggests that the original deposit was
limestone (CaCO₃) which later was dolomitized and at the time of
dolomitization silification took place forming chert. Dolomite was not
replaced by the silica but CaCO₃ was replaced that is why dolomite
rhumbs are seen arrested in the chert (Dietrich et al., 1967). It proves that
dolomitization was interrupted by silification (it means that
undolomitized part was silified while dolomitized part remained
unchanged).
3.6. MINERALOGY AND GEOCHEMISTRY

X-ray diffraction method was used to study the mineralogy of the phosphorite samples. Natural samples were irradiated with CuK radiation for six hours at 35 kv and 20 mA. The identified phosphate minerals are mostly carbonate fluorapatite. Other minerals include quartz, calcite, dolomite, feldspar, montmorillonite, some mica (Fig. 22.a,b).

Chemical compositions from Kalal and Lambidogi areas of Hazara phosphorite is given in the table 5 & 6 respectively. High silica content in most of the samples is due to association of apatite with chert and high MgO content in other samples is due to its association with dolomite. Generally the MgO values in the other phosphorite samples are low.

P2O5 has got strongly negative correlation with SiO2 in Kalal and weakly negative in Lambidogi area. As the ionic radii of Si4+ and P5+ is same, therefore, they replace each other because diadochic relationship exists between them (Krauskopf, 1967). By the precipitation of P2O5, SiO2 is gradually removed. The removal of SiO2 by P2O5 appears more significant in Kalal than in Lambidogi area. There is an inverse behavior between P2O5 and MgO and between CaO and MgO in both the Kalal and Lambidogi phosphorites. The Mg2+ ions hinder the enrichment of Ca2+ for positions in the apatite structure (Martens & Hariss, 1970).
Fig. 22.a

Fig. 22.b
### Chemical Analysis of Phosphate samples from Kakul area

(Chau and Ahmed, 1991)

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## Table-6

Chemical Analysis of Lambidogi Area, Hazara

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Fluorine has also been reported from these phosphorites usually as fluor spar. Generally fluorine is bound to the apatite and the F/P₂O₅ ratio varies between .08-.10 which is comparable with F/P₂O₅ ratios of Precambrian phosphate deposits of Upper volta basin, West Africa (Lucas, 1980).

3.7 DISCUSSION

Field and laboratory data collected during present study suggest that the depositional environment of Hazara phosphorites is best explained by Riggs’s (1979) model which states that biologically stressed shallow water environments received bacteriologically precipitated mud as well as other biologically produced phosphate grains. The bentonic community populating these muds, ingested and excreted the muds as fecal pellets, while other biological and physical processes produced intraclasts. Under high energy conditions, very locally, some of the mud was aggregated to produce pseudo-ooids.

It is proposed that Hazara phosphorites were formed in greater depths than the eventual site of accumulation and the oceanic upwellings are thought to be one of the major mechanisms for recycling these phosphorites to the present site of accumulation. This is supported by the fact that phosphate grains in Hazara contain organic matter and pyrite which suggest their formation in anoxic conditions (Riggs, 1979, a,b). A number of other workers for example Kazakov (1937), McKelvey et al (1953) and Sheldon (1984) have also described a close association of the upwelling with phosphatic sediments.
The phosphorite strata show cyclic repetition at Kailal and other localities in Hazara. This cyclic nature of vertical sequence most likely reflects change in conditions due to transgressive and regressive phases (Notholt, 1976). It appears that sea level changes (transgression & regression) during Paleozoic period have controlled the formation of Hazara phosphorite facies within broad shelf setting. It coincided with the reworking and winnowing processes which subsequently lead to the formation of economically important deposits in the world (Thomburg, 1990). The phosphorite deposits of Hazara belonging to early Paleozoic age also appear to have formed in the same paleogeographic setting.

The marine phosphorites have also been classified into geosynclinal and platform types (Kazakov, 1937 & Notholt, 1976). The absence of black shale sequence from Hazara phosphorites suggests their platform type of origin. Further, in Hazara deposits, platform type phosphorite lithofacies like sandstone, dolomite, red beds (lenticular) calcareous shales and siltstone are common. Though, any evaporite mineral like gypsum has not been noticed in these phosphorites, but there is a possibility that it occurs in association with dolomite and other rocks and may be present there in the form of ultra microscopic intra crystalline inclusions which are sufficiently small to be seen under the microscope (Beales and Hardy 1980). The presence of montmorillonite type of clay in Hazara phosphorites further supports the formation of these phosphorites in the platform basins.

The relic grains of calcite suggest that these dolomites are of replacement origin as has been agreed by many geologists that most of the
world's dolomite deposits are secondary in origin in the sense that some sort of carbonate sediment precursor existed prior to replacement (and often cementation) by dolomite (Land, 1980). As no evaporites can be observed in these dolomites or in the overlying sediments, it seems that complete dolomitization of entire Sirban Formation has taken place without the deposition of evaporite minerals as in shallow subsurface dolomitization of Hansen Creek Formation of Central Nevada (Dungan and Olson, 1980). Hence the dolomitization of Sirban Formation took place post depositionally and the hyperhaline brine was unlikely the agent responsible for this dolomitization. Formation of dolomite took place after the deposition of carbonates in shallow marine shelf environments but before burial compaction could produce diagnostic features like styloleites.

The presence of dolomite rhombs in the shert of Abbotabad Formation show that when dolomitization was going on, silica entered to interrupt dolomitization and calcium carbonate was replaced by silica and overgrowths developed on the quartz grains while the dolomite which was formed up to that time was not altered by silica.

Phosphorites and its associated rocks at Kala and other areas in Hazara are highly folded, faulted and thrusted. Tectonics has played an important role in deforming the strata in the area (Khan & Ahmad 1991).

Hazara phosphorite resemble Bijnor district phosphorites of western Rajasthan and Tal phosphorite deposits of Missouri Garhwal (India). All such phosphorites commonly contain carbonate floccular and associated authigenic minerals like dolomite, calcite, quartz, pyrite, some ferruginous and clay minerals. The petrographic study reveals that sparse
occurs mainly as (i) microphorite and (ii) as pellets of various shapes and size. Further, the host rocks of these phosphorites broadly constitute dolomite, chert, siltstone, shale and limestone.

The field and laboratory data published so far suggest a close relationship among these phosphorite deposits and also support the view about a Cambrian-Ordovician littoral sea bordering the north Indian cratonic mass extending from western Rajasthan in the west, Kashmir and Hazara in NNW, Garhwal and Nepal Himalayas in the north. The western margin of this basin seems to be reflected in the sedimentary package of Biaunia Formation, the NNW section by the phosphate bearing formation in Abbottabad, while the northern coast received sediments in the Cambrian Tal basin of the Garhwal Himalayas. This correlation shows the synchronicity of phosphate precipitation events during lower Paleozoic times.
Chapter-4

INDUSTRIAL APPLICATION
Chapter-4

INDUSTRIAL APPLICATION

4.2. PHOSPHATIC FERTILIZER INDUSTRY IN PAKISTAN

As Pakistan is an agricultural country, so our aim must surely be one of increasing self-reliance, and in terms of agriculture, to ensure an adequate supply of food grain to fulfill the needs of country's population. It is a fact that the route to such self-reliance in agriculture is by the use of appropriate fertilizers to produce good yields.

Phosphorus, potassium and nitrogen are all nutrients critical for plant growth. Of these, nitrogen is present in excess in the atmosphere and if necessary, can be fixed artificially by well-known industrial process. Potassium is available in many large-scale geological evaporite deposits but phosphorus is available only by exploiting the phosphate deposits, which are non-replenishable are not much abundant to be wasted, so must be used most carefully. With the increasing rate of population of our country the intake of fertilizer is also increasing.

Pakistan has got huge reserves of probable 20 million tons of rock phosphate in Hazara area (SDA report 1994) which are enough to meet the demand of phosphatic fertilizer. The proven reserves at Kalal are about 17,000 tons with an average grade of $P_2O_5 = 26.05\%$ and $SiO_2 26.8\%$ (Table-5). SDA is mining at Kalal with the annual production of 41,290 tons. This ore is used in the manufacture of phosphatic fertilizers (Table-7).
Table 7
Phosphatic Fertilizer Production in Pakistan (in thousand tons).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Super Phosphate</td>
<td>2,099</td>
<td>2,109</td>
<td>1,898</td>
<td>2,306</td>
<td>297</td>
</tr>
<tr>
<td>Nitro Phosphate</td>
<td>331</td>
<td>333</td>
<td>321</td>
<td>310</td>
<td></td>
</tr>
</tbody>
</table>


In order to meet the requirements of fertilizers, raw phosphate and other fertilizers are imported from Jordan and Morocco at huge costs (Table 8).

Table 8
Import of Chemical Fertilizers (including phosphatic fertilizer) in Pakistan.

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantity (million tons)</th>
<th>Value (Rs. in million)</th>
<th>Offtake Rate (000 M.T.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988-89</td>
<td>752</td>
<td>3,534</td>
<td>1,740</td>
</tr>
<tr>
<td>1989-90</td>
<td>1,127</td>
<td>4,437</td>
<td>1,890</td>
</tr>
<tr>
<td>1990-91</td>
<td>1,177</td>
<td>5,911</td>
<td>1,893</td>
</tr>
<tr>
<td>1991-92</td>
<td>1,269</td>
<td>6,367</td>
<td>2,884</td>
</tr>
<tr>
<td>1992-93</td>
<td>1,255</td>
<td>6,438</td>
<td>2,068</td>
</tr>
</tbody>
</table>

Manufacture of fertilizers is by far the largest consumer of phosphate rock, probably about 81% of the world phosphate is used in making fertilizer or used as fertilizer directly in developing countries of Asia where the demand is expected to rise at a rate of about 4-6% per annum. World grain consumption is directly related to the world population, which is growing. Hence with the passage of time the consumption of fertilizers will also increase.

4.2 PROCESSING

In case of Kedal where most of the high grade ore has been utilized, economic process will have to be sought before the bulk of "low grade" ore can be used. This run-of-mine phosphate rock is low in P₂O₅ content and need to be upgraded to the requirements of fertilizer industry. Sazhad Development Authority is forced to do selective mining in order to meet the demand of the fertilizer industry. Therefore, beneficiation studies are imperative to use our phosphate deposits in a right way.

4.3 DIRECT APPLICATION

Many countries like India, Sri Lanka and United Kingdom have undertaken successful studies on using rock phosphate as direct fertilizer. Direct application of rock phosphate could offer some advantages, particularly for fine-rooted crops.

Studies should be carried out on the behavior of phosphate in soil, crop requirements for phosphate and the interaction of these factors (Mare P.H.I., 1993). In direct application, the solubility of rock phosphate is
small, surface area is important to ensure maximum contact between particles and soil solution. Hence, the material should be finely ground, scattered and incorporated into the soil, in contrast to soluble fertilizers for which very close contact with soil causes faster formation of less soluble reaction products (Mare, P.H.L., 1993).

In order to obtain acceptable efficiency from the direct application of ground phosphate rock, we have to undertake the studies of soil and the type of rock used in different parts of the country.

4.5 ENVIRONMENTAL PROBLEMS

The growing population of the world and particularly of Pakistan will continuously increase the use of fertilizers, to grow more crops, and particularly of phosphatic fertilizer. As phosphate is to be mineral and exploited so it creates some environmental problems.

During beneficiation process particularly by sizing and flotation techniques, extremely fine-grained phosphatic "waste clay" is produced which is a serious environmental problem of the fertilizer industry. The problem is that this clay is so fine that it takes years to settle down (Jarvis et al., 1994).

About 70% of the phosphate mined is initially converted to phosphoric acid and the phosphatic fertilizer industry is the largest consumer of sulphuric acid in the world (Table-9) (Evans, 1993).

This process also results in the production of substantial quantities of a by product gypsum known as "phosphogypsum" (Jarvis et al., 1994). Three tons of gypsum are produced for every ton of phosphoric acid. Besides the obvious waste of a potentially valuable by product and the
unsightly physical appearance of the stockpiles, the main problem associated with phosphogypsum storage is the potential effect on the surrounding environment, especially on air and water resources in the vicinity of gypsum stacks (Koulischer, 1980). Fluorine is emitted to the atmosphere and ground water is contaminated with radium, sulphate and fluoride due to backflow by process water or rainwater (Nisonger, 1988).

In Florida mining areas other U-series nuclides associated with phosphogypsum have been reported in dangerously high concentrations in shallow ground water (Harada et al., 1989).

### Table 9

**Phosphate Fertilizer Consumption, Crop Years 1987-91**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>4,262</td>
<td>4,380</td>
<td>4,349</td>
<td>4,551</td>
<td>4,344</td>
</tr>
<tr>
<td>Latin America</td>
<td>2,753</td>
<td>2,600</td>
<td>2,728</td>
<td>2,404</td>
<td>2,222</td>
</tr>
<tr>
<td>W. Europe</td>
<td>5,177</td>
<td>5,238</td>
<td>5,165</td>
<td>4,991</td>
<td>4,611</td>
</tr>
<tr>
<td>E. Europe &amp; USSR</td>
<td>11,150</td>
<td>11,144</td>
<td>11,269</td>
<td>10,556</td>
<td>9,191</td>
</tr>
<tr>
<td>Africa</td>
<td>1,178</td>
<td>1,137</td>
<td>1,171</td>
<td>1,077</td>
<td>1,064</td>
</tr>
<tr>
<td>Asia &amp; Oceania</td>
<td>10,137</td>
<td>11,984</td>
<td>13,280</td>
<td>13,814</td>
<td>14,590</td>
</tr>
<tr>
<td>Total Production</td>
<td>34,658</td>
<td>36,683</td>
<td>37,962</td>
<td>37,393</td>
<td>36,023</td>
</tr>
</tbody>
</table>

4.6. MEASURES FOR DEVELOPING PHOSPHATE FERTILIZER INDUSTRY

The proved reserves would be mined on pure scientific grounds in order to carefully exploit these reserves to obtain maximum benefits. As the strata are deformed as mining should be accompanied by detailed sampling and industrial testing to avoid selective mining which has been carried out in the past in Kokul where P205 rich ores are mined and the low grade is left.

Detailed petrographic, mineralogical and geochemical studies are necessary to carry out processing of Hazara phosphate so that it competes well with the imported rock phosphate in quality. Major impurities identified in Hazara phosphorite are silica, magnesium oxide and iron oxide. If these steps are taken and adequate funds are provided for mining the known deposits and exploring/proving further deposits in Hazara district, the production can reach of several lakh tons per annum.

There is one good example of Sandak where government is taking interest and investing billions of rupees. As Pakistan is an agricultural country, no government should take interest in promoting fertilizer industry. Pakistan is a food grain importer and this burden will become unbearable in the years to come. Sarhad Development Authority should be supported both technically and financially by provincial and federal governments in order to improve the mining. Some research and developmental support must be given to develop and equip these phosphate mines to increase the phosphate production.
Chapter 5

SUMMARY AND CONCLUSIONS
Chapter-5

SUMMARY AND CONCLUSIONS

- Hazara phosphorites are the only known commercially workable phosphate deposits in Pakistan. The sediments containing these phosphorites are highly folded and faulted thus disturbing the geology of the area. Due to tectonic disturbances these phosphate deposits are disrupted into small deposits. Phosphorite occurs in two Formations: i) a lower horizon in Abbotabad Group which is exposed at Katul, Laghavan, Lambidogi, Tanawal, Sirban and Scioangali. ii) an upper horizon which occurs in Hazira and Culmian members of Tanawal Formation and is exposed at Dadola and Sirbas areas.

Various rock units exposed in the area are phosphorite, chert, dolomite, siltstone, shale, limestone and sandstone ranging in age from Jurassic to Precambrian.

Following conclusions can be drawn on the basis of the present studies:

- Dolomite occurs in Sirban unit which is well exposed and is thick enough to be given the status of a Formation.

- The petrographic studies show that Hazara phosphates formed originally as orthochemical phosphate (phosphatic mud). Later, when high energy conditions prevailed, reworking of this...
authigenic microcrystalline phosphatic mud took place and pellets and pseudo-ooids were formed.

* Dolomite is formed from the replacement of the pre-existing calcite or limestone and thus is of secondary origin and this dolomitization has taken place in more than one phases. The presence of stylolites proves that the diagenesis took place after the formation of dolomite. Dolomitization has been interrupted by silicification.

* X-ray diffraction studies show the presence of carbonate fluorapatite \([\text{Ca}_10(\text{PO}_4)\text{F}_2]\) mostly as the phosphate mineral, while other minerals are quartz, calcite, dolomite, feldspar, montmorillonite, etc.

* Chemical composition of Kalal phosphate samples show high Si and Mg content which may be due to its association with chert and dolomite respectively.

* The cyclic repetition of strata at Kalal and other localities suggest the transgression and regression have controlled the formation of Hazara phosphorite facies within broad shelf setting.
REFERENCES

1 A report on exploration and development studies of Hazara rock phosphate by British Mining consultants and Sarhad Development Authority (1977).


