CHAPTER IV
PETROGRAPHY
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An attempt has been made to examine closely the petro-mineralogical characteristics of the phosphorites and their host rocks. A detailed thin section study of about 59 representative samples collected from mine workings as well as from their sections of the exposed outcrops at Maldeota and Durmala, was made. The study has been useful not only for understanding the stages involved in mineralization but also for the collection of samples for geochemical studies.

(1) PHOSPHORITES:

Phosphorite usually contains a number of apatite like phosphate minerals which have been reported in literature and are designated by subspecies: pedolite, dahlite, francolite, staffelite, kurskite, grodnolite, wilkeite, ellesstadite and morinite. Due to such a wide mineralogical variations collophane, a generic name of phosphorite, is often used in literature. The mineral composition of composite phosphorite samples from Maldeota is given below:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collophane</td>
<td>45.50</td>
</tr>
<tr>
<td>Calcite</td>
<td>28.30</td>
</tr>
<tr>
<td>Quartz</td>
<td>7.9</td>
</tr>
<tr>
<td>Pyrite</td>
<td>5.6</td>
</tr>
<tr>
<td>Sericite-muscovite clay</td>
<td>3.4</td>
</tr>
<tr>
<td>Dolomite</td>
<td>1.2</td>
</tr>
<tr>
<td>Limonite</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Collophane:

Collophane happens to be the dominant mineral of phosphorite of all varieties in this area having a composition $3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{Ca}((\text{CO}_3\text{F}_2\text{O})\text{H}_2\text{O})$ (see Kerr, 1959) i.e. carbonate hydroxyl fluorapatite. The colour of collophane ranges from greyish yellow to greenish black. It contains dot like inclusions without any preferred orientation: This may be due to dark coloured ferruginous material. It is microcrystalline in nature and isotropic to weakly anistropic under crossed nicols (Plate-IV , Fig.1 & 2).

Collophane occurs in the form of ovules, pellets, lenticles, aggregated ovules, micro-aphanitic mass, superficial ovulite, nodules and oolites.

The ovules are isolated bodies that are circular, ovoidal to elongated and widely scattered in the matrix. They range in diameter size from 4 microns to 89 microns but the average is 30 microns. The ovules consist of two distinct parts - the nucleus, and the envelope. The nucleus comprises of detrital silica and occasionally detrital carbonate. The envelope is essentially a structureless body. The margins of the ovules are regular, uniform and complete but often crenulated, which may be due to the replacement phenomenon (Plate- V , Fig. 2 ).

The pellets made up of dark grey to brownish grey isotropic collophane are enclosed in a carbonate matrix. The boundaries between these pellets and the groundmass are generally irregular though sharp with no visible replacement
(Plate-IV, relation (Fig.1 & 3). Inclusions of angular small elastic quartz grains are seen in these pellets.

The lenticles are elongated and continuous bodies. These may be formed due to i) elongated nature of ovular bodies and ii) diagenetic stretching of collophane.

The ovular bodies usually coalesce together and give rise to aggregate ovules. The dark coloured varieties appear to be cemented by the light coloured ones (Plate- V, Fig. 2 ). Microaphanitic mass is an amorphous looking collophane of matrix (Plate- VI, Fig. 1 ). Superficial ovulite has only one concentric layer around the carbonate nucleus. At places the concentric layer is discontinuous as a result of incomplete oolitization.

Nodules are in the shape of smaller ovoids which are composed of dark grey to greyish-brown anisotropic collophane embedded in a cementing material consisting of calcite (Plate- V, Fig. 2 ). Oolites have numerous concentric layers on the envelope having nucleus of carbonate (Plate- V, Fig. 1 ).

**Texture :**

The different textures encountered in the phosphatic material are described as ovulite, microaphanite, interstitial collophane and massive collophane. Ovulite is composed of well sorted ovoidal to spheroidal and elongated aggregate masses possessing a modal diameter of 0.0002 m. to 2 mm. (Plate- V Fig. 2 ). Microaphanite is composed of interlocking grains
having sutured arrangement and the modal diameter is less than 0.0002 mm. (Plate- VI, Fig. 1).

The interstitial collophane is seen to occur in the voids between calcite, quartz and feldspar grains. The collophane is isotropic and greenish in colour under crossed nicols (Plate- IV, Fig. 4). Massive collophane is dark greyish in colour and at places replaces the calcite. This variety is intensely intersected by numerous calcite veins (Plate- VI, Fig. 3).

Dahlite:

Dahlite (intermediate composition between hydroxyl-apatite) $3Ca_3P_2O_5\ Ca(OH)_2$ and Podolite $3CaP_2O_5\ CaCO_3$ - Winchell) is anisotropic mineral and occurs in fibrous sub-radiating form surrounding the collophane (Plate- IV, Fig. 2) in nodular and oolitic varieties of phosphorites. Dahlite is colourless to pale-brown and has moderate relief. The birefringence is weak and interference colours are bluish grey to white of first order. Dahlite is secondary mineral much like apatite having parallel extinction. Dahlite on the outer margins of collophane seems to have developed due to recrystallization and alteration of collophane.

Gangue Minerals:

The predominant gangue minerals, associated with phosphate minerals, include calcite, dolomite and quartz.
Calcite:

Calcite is a carbonate gangue mineral of Mussoorie phosphorites. It has the composition \( \text{CaCO}_3 \). It is usually colourless to light grey in colour and occurs as coarse particles in the form of rhombohedral crystals which are usually subhedral, occasionally anhedral and rarely euhedral. The are equidimensional and the polysynthetic twinning is parallel to the long as well as short diagonal of rhombs. The crystals are tightly packed with slight sutured margins that could be the effect of solution pressure. It is recognised by its light birefringence, perfect rhombohedral cleavage and marked change in relief on rotation of stage in plane polarised light. Calcite also occurs as micrite which is a lime-mud or its indurated equivalent either in crystalline or fine grained forms with diameter not exceeding 0.005 mm. in size. This interference colour is pearly grey to white of the high orders. The extinction is symmetrical to the cleavage traces. Calcite veins cutting across the phosphate matrix are seen in some of the thin sections (Plate- VI, Fig. 2 & 3).

Dolomite:

Dolomite is also a gangue mineral having the composition \( \text{CaMg(CO}_3\text{)}_2 \). Dolomite also shows almost the same optical characteristics as that of calcite and varies in size from 0.38 to
1.76 mm. The crystals are usually subhedral to euhedral and twin lamellae parallel to short diagonal. It has rhombohedral cleavage, high birefringence (light white) and marked change, in relief on rotation of the stage in plane polarized light (Plate- V Fig.1 & 3).

**Quartz :**

Quartz is the dominant gangue mineral of the phosphorite and is distributed in the entire rock mass with the major part in the matrix. The grains are angular to subrounded and range in size from 4 to 45 microns. Quartz vein is seen in phosphate matrix (Plate- VI, Fig. 1 ). It occurs in different forms associated with collophane, viz., i) as microcrystalline silica showing a mosaic pattern with tortuous contact. Secondary overgrowth of silica is also observed (Plate- V, Fig. 4 ); ii) as cryptocrystalline silica which is fine grained with wavy extinction; iii) as fibrous silica occurring in the form of microphanitic mass and is found usually in the matrix; and iv) as detrital quartz which occurs as inclusions in the matrix and secondary overgrowth is also noticed.

**Ferrous Minerals :**

Pyrite being intimately associated with phosphate, is the most common iron mineral present in the unweathered rock phosphate. It occurs as subhexagonal lumps and tortuous streaks and ranges in size from 10 microns to 89 microns, the
average being 25 microns. In polarized light, the colour is steel grey having high relief and is isotropic under crossed nicols. In reflected light, it is brass-yellow in colour.

Limonite is another ferrous mineral which is present in minor amount. The colour of limonite in polarized light is light brown to orange and is isotropic in crossed nicols. Limonite is generally the alteration product of pyrite and is thus found more in the weathered samples. Pyrite/limonite ratio could serve as an index of weathering.

Accessory Minerals:

The mosaic is constituted mainly of carbonate minerals together with minor amounts of feldspar, muscovite and sericite. These minerals occur as shapeless plates and elongated laths. Sericite and muscovite are generally colourless to yellowish in colour (Plate-IV, Fig. 4).

Replacement: The mutual replacement of phosphate, carbonate and silica has been noticed in these sediments. However, carbonate replacement is very common and discussed depending upon the minerals involved.

The carbonate material penetrates into ovules of collophane and as the intensity of replacement increases it becomes thicker replacing the phosphate material completely (Plate-VII, Fig. 2). When intensity of replacement is low the phosphate material is partially replaced (Plate-VII, Fig. 2).
In weathered rock phosphate feeble carbonate replacement of silica is observed possibly due to leaching out of carbonate by chemical weathering, thus a ratio of carbonate and silica in such rocks along with pyrite/limonite ratio could illustrate the extent of weathering.

The replacement is also observed in matrix. At places the phosphate pellets are embedded in a carbonate matrix which indicates a replacement of original phosphate by carbonate or intra-basinal transport of earlier formed phosphate pellets and their redeposition contemporaneous with the precipitation of chiefly carbonate mud (Plate- IV, Fig.1 & 3).

(2) HOST ROCKS :

The associated rocks of Mussoorie phosphorites were also studied for detailed petromineralogical characters. The thin sections of all the lithological units belonging to the different blocks were investigated with a view to note the variations in the nature of the rocks belonging to these blocks.

Cherty Limestone :

It is dark grey in colour. The rock is close grained, compact and fine textured in nature. The fine grained and compact calcareous material is associated with chert. The detrital grains of quartz varying between medium to fine in size exhibit the considerable rounding. The textural features of this rock type remain almost the same in all the blocks.
Calcite is colourless. The grains of calcite vary between fine to coarse aggregates. The grains are mostly anhedral (Plate-VII Fig. 4). The cryptocrystalline variety of silica occurs in the form of chert. The fine grains of quartz are interlocked in the calcareous material. The quartz grains are anhedral. Quartz also occurs as secondary veins and appears to traverse the rock.

Limonite occurs as a brown colour cement around the detrital grains of quartz.

**Dolomic Limestone:**

It is grey to bluish grey, massive, compacted rock with coarse grains of calcite and dolomite, which are anhedral in shape and constitute the bulk of these rocks (Plate-VIII, Fig. 1).

**Black Shale with Siltstone Bands:**

Shale is black in colour. It is indurated and banded sediment composed of finely divided mineral matter of clay grade and with varied composition. It is very close textured rock. The shale is alternated with siltstone bands which are also fine grained.

Quartz is fine grained colourless mineral. It constitutes both shale and siltstone. The opaque cubes of pyrite constitute the bulk of heavy residual material, which is the characteristic feature of this rock (Plate-VIII, Fig. 2 & 3). Low calcite, illite and other clay minerals, feldspar and sericite have been identified in these carbonaceous shales. Phosphatic nodules occur in the carbonaceous shales at places.