CHAPER - 7

HEAVY MINERAL ANALYSIS

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Detrital sediments are generally composed of grain density. Most sandstones contain certain traces of minerals with specific gravities between 4 and 5. The heavy minerals, as they are called, possess a higher specific gravity than quartz (2.65) and are thus separated by using bromoform, or other liquid, with specific gravity 2.89. Therefore, heavy mineral can be defined as minerals heavier than bromoform. According to Pettijohn (1984), "the minerals of the pre-existing rocks, surviving destruction, mechanical and chemical action or interstratal solution are the heavy minerals". More than hundred such mineral species have been identified, but they do not constitute more than 0.1-0.5% of the terrigenous fraction of sediments. Because of their durability and high specific gravity, they are transported along larger detrital grains; therefore, the sand fraction between 88 to 250 microns size yield maximum heavy minerals (Sinha and Khan, 1965).

This heavy fraction of the sediments helps in understanding lithology of the source rocks, differential stability of the source rocks, resistance to long continued abrasion, hydrodynamic conditions, and post depositional survival function. Heavy mineral show considerable variation because of differential physical stability during transport, differential chemical stability and sorting of mineral species with different specific gravity. The variation in distribution of heavy minerals helps in establishing the erosional and tectonic history of basins (Van Andel, 1959). The importance of heavy mineral assemblages in unfossiliferous sedimentary rocks undisputed for the sediments originated and accumulated under the condition of active erosion, short transportation and rapid deposition. For such sediments, the heavy mineral assemblage directly reflects
the petrography of the source area. The study of heavy minerals also enables to classify the sedimentary rocks (Sinha, 1980). The heavy minerals are also utilized for local and regional correlation (Mathur and Evans, 1964). It as well as helps in knowing the physico-chemical conditions of the source area. The heavy mineral assemblages present in the sediments depends upon interactions between mineral gravity, particle shape, availability of size to the transporting agent, hydraulic selectivity and provenance (Sinha and Sashtri, 1973).

Heavy minerals is immencely helpful in the provenance study of relatively immature sandstones; because, they typically contain the greatest diversity of heavy minerals (Owen, 1987).

7:2 METHODS OF STUDY:

All the samples subjected to mechanical analysis were utilized for the study of heavy minerals content. The heavy mineral separation was carried out by conventional "Funnel separation" method (Milner, 1952). Though the heavy minerals were studied in fraction wise basis, but only the total results obtained for each sample have been given. Details of the method adopted for this studies have been given in chapter 3 of this text.

7:3 OBSERVATION:

The heavy minerals suites of the Surma and the Tipam groups of sandstones consists of almost similar types of heavy minerals. The two sandstone units reveal the occurrences of opaques, Zircon, Tourmaline, Rutile, Garnet, Epidote, Kyanite, Zoisite, Staurolite, Andalusite, Silliminite, Chloride, Chloritoid, Muscovite, Biotite and Hornblende. Both the sandstone units are dominated by opaque minerals. The Surma sandstones containing higher percentage of epidote and garnet than the Tipam sandstones. The detrital characters
of these heavy minerals found in the Surma and Tipam sandstones are
given below. Details morphology of the zircon and tourmaline has
been discussed separately. The number of percentages and frequency
distribution of each mineral of different samples of both the units
are given in table 24 and table 25 in the column A and B
respectively.

OPAQUE MINERALS ::

The opaque minerals constitute the major bulk of
the heavy concentrates in all samples. This group of minerals
consists mainly of magnetite and few ilmanites, pyrite and limonite.

The opaque minerals of both the sandstone units
show wide variety in forms, from euhedral to enrhedral. Magnetite
possesses a redish brown colour, ilmanite has a steel grey lustre
and pyrite shows a brass yellow colour under reflected light. On
passing the heavy concentrates through an electromagnetic field a
considerable amount of grains were found to be attracted. This
indicates the presence of a high amount of magnetite within the
opales.

On the other hand, to their irregular grain shape
and non-availability of any diagostic petrographic properties, made
it difficult to identify and count different opaque separately. These
unidentified opaque minerals are very negligible and so, all the
ilmanite, magnetite, pyrite and un-identified opaque are counted
together and grouped under "opaque minerals". The total opaque
varies from 24.81% to 36.20% and in frequency from 6+ to 7- in
Surma sandstones, and in case of Tipam sandstones it varies from
18.87% to 35.54% and in frequency from 6+ to 7-.

ZIRCON :

The Zircon population varies between 2.58% to 7.05%
and in frequency from 3 to 5 for the Surma sandstones & for the Tipam
sandstones it varies from 1.50 to 9.52% and in frequency from 2 to 5. No consistency has been noticed in the case of shape of zircon grains. In some samples of both the units broken grains of zircon observed. Some samples shows euhedral grains without core, and these are followed by euhedral grains with core (Plate 7:1). Some of the euhedral grains passes a dark boarder with colourless core and in most cases the dividing line between the darker and colourless zone is distinct but for some cases it is very hazy.

Various colours of the zircon grains are observed in the Surma and Tipam sandstones. The colourless grains are dominantly present followed by hyacinth and malacone grains (Plate 7:2 and 7:3). Some grains shows cloudy appearance. This dusky appearance might be due to weathering or some fluid injection (Awasthi, 1961).

Both the groups shows occasional inclusion in the zircon grains. Some zircons contain only opaque inclusions, some contains non-opaque (Plate-7:4). The shape of the inclusion minerals are spherical, needle shaped or irregular. Some gas bubble like features within zircon grains are noted.

Most of the zircon grains are without any crystal faces. A few grains possesses certain crystal faces development. Minor amount of zircons are found with all clearly developed crystal faces (plate- 7:1). It can be said that majority of the zircon grains originally possessed good crystal faces. But due to transportation, abrasion might have affected the grains resulting the grains to be present without having any crystal faces.

Very few grains show overgrowth whose shapes are round, having irregular or smooth outline. These are the authigene growth formed due to the action of interstratal solution of the same molecular composition (Plate 7:5). Twinned zircon grains are also observed (Plate-7:6).
ELONGATION VALUES OF ZIRCON GRAINS:

The average length 'L', breadth 'B' and elongation ratio 'ER' of the zircon grains have been determined for different samples of the Surma and Tipam Groups of sandstones (Table 26). Also their frequency distributions are given in Table 27 and 28 for the Surma sandstones while for the Tipam sandstones are given in Table 29 and 30. The average length and breadth of the zircon grains of the Surma sandstones varies from .02 to .13 and varies from .01 to .10 respectively, while for the Tipam sandstones average length varies from 0.10 to .20 and average breadth varies from .01 to .11. Elongation ratio for the Surma, varies between 0.20 and 2.33 and for Tipam sandstones ranges between 0.15 and 1.92. While measuring the length and breadth of zircons, very often broken grains are encountered, they are not counted. The zircon grains are more prone to break across the length during transportation than along to the breadth because of its elongated nature. As a result, the measured values of length in zircon is always less than the original value in comparison to the breadth of the grains which lower the elongation ratio of zircon.

The colour of zircon is less important in inferring about provenance. But the absence of inclusions in most of the zircon grains indicates their derivation from pegmatites. Presence of zircon grains with inclusions indicates their derivation from igneous and metamorphic sources also. The presence of euhedral grains represents their derivation from igneous and metamorphic rocks and less transportation from provenance to the site of deposition. The presence of rounded grains of zircon indicates sedimentary source as well as partly due to transportation effect. Presence of broken zircon grains also indicate about the transportation. The presence of the higher percentage of zircon grains without crystal faces indicates that the grains were subjected to maximum wear and tear by the dynamics of the depositing agencies.
From the study of the zircons, it may be assumed that zircon grains of the Surma and the Tipam groups of sandstones might have been derived from igneous and metamorphic terrains. The sediments were derived from nearby source but were later affected by the action of the depositing agencies.

TOURMALINE:

The tourmaline populations of the Surma sandstones vary between 9.48% to 13.79% and in frequency from 5 to 6— while the Tipam Sandstones show their variation from 5.42% to 17.40% and in frequency from 4 to 6—. Various colours have been exhibited by the tourmaline grains. Tourmalines show pale brown to deep reddish brown to almost black in colour (Plate 7:7); some grains show light green to deep green and to deep greenish black colour (Plate 7:8). Other colours of the grains include Pink, Blue, lemon-yellow and colourless character (Plate 7:9). The pale brown grains show strong pleochroism from light pale brown to dark brown. The blue variety (indicolite) exhibits weak pleochroism in the shades of blue (Plate 7:10). The mineral possess high relief and moderate birefringence. In deeply coloured grains, interference colours are masked by the body colours. Pale brown to deep reddish brown coloured grains of tourmalines predominate over the others. The blue (colour for the presence of Na-Fe-Li in excess) and pink (colour for the presence of Li in excess) tourmaline grains can be grouped under "Rubellite" as 'Indicolite' and "Rubellite" respectively. Colourless tourmaline normally belongs to 'Dravite' (due to excess of pure Na) and green tourmaline (colour for the presence of Ca-Na-Fe-Li in various proportions). Deep brown to black tourmalines (colour for the presence of Fe) include in schorlrite group. Tourmalines, from both the sandstones groups, show inclusions. Inclusions includes rod-shaped and often microliths of opaque minerals (plate 7:11). It is found that most of the inclusions are quartz, magnetite, zircon, and the opaque minerals are tentatively identified as iron oxide.
The shape of the tourmaline grains of the Surma and the Tipam sandstones are found to be prismatic and round (Plate 7:12). Besides these, broken grains of tourmalines also presents. It may be said that most of the broken and sub-rounded tourmaline grains were derived from idiomorphic grains. Some of these idiomorphic grains were abraded to rounded form along with some fragmental grains when they were transported from the parent rock to the area of deposition. The round tourmaline, in later stage, were broken on way of transportation, resulting angular to subrounded fragmental grains of tourmaline. The broken grains resulted due to high degree of wear and tear indicating rough action during the time of transport like wave action, roughness of the floor and higher load action of the transporting media. Authigenic growth in the tourmaline grains occurs impersistantly in the Surma and Tipam group of sandstones. Generally the authigenic portions are colourless, while the original grains are mostly coloured and pleochroic (Plate 7:13).

In the Surma sandstones the length of the tourmaline grains ranges from 0.01 to 0.14 and the breadth from 0.01 to 1.55. The Tipam group of sandstones shows variation in length from 0.01 to 0.04, breadth from 0.01 to 0.11 and elongation ratio ranges in between 1.30 to 2.66.

From the morphological study of the tourmaline grains of the Surma and the Tipam sandstones, conclusions may be drawn regarding the origin and paragenesis of the sandstones, that brown to black, green, pink coloured and colourless tourmaline, prismatic, angular, with inclusions indicates their derivation from granitic and metamorphic terrain. Where as blue and dark brown coloured, prismatic and idiomorphic tourmaline grains together with inclusion free grains indicates a pegmatite injected metamorphic terrain. The presence of round and broken tourmaline grains suggest their derivation from the abraded detritals of many mixed typed. The authigenic overgrowths in the tourmaline grains indicate post depositional diagenetic changes. All
these morphological characters of tourmaline grains indicate the much affinity towards metamorphic source rock even though igneous source cannot be ignored.

**RUTILE:**

Rutile is very rare in the Surma and the Tipam groups of sandstones. The minerals bear blood red to reddish brown colour and show weak pleochroism. It shows oval shaped but occasionally elongated (Plate 7:14). Rutile in the Surma sandstones varies from 0.57% to 1.72% and in frequency from 1 to 2. The Tipam Sandstones show variation from 0.60% to 2.79%.

**GARNET:**

It is most predominantly occurring in all the analysed samples of both the Surma and the Tipam sandstones. Their occurrence varies from 16.80% to 30.95% with frequency from 6 to 7 in the Surma and from 3.40% to 20.00% and in frequency from 5 to 6 in the Tipam sandstones. They are mostly pink but some of the grains are colourless. Garnet occurs as irregular and sub-angular; sometime some well rounded and crystalline grains are also well observed (Plate 7:15a and 7:15b). The mineral is isotropic with high relief. Fractures also present. Inclusions of both opaque and non-opaque minerals are observed in the grains. Most of the grain surfaces appeared oily; also shows overgrowth (Plate 7:16).

**EPIDOTE:**

It occurs as irregular, angular to sub-angular, colourless to typical pistachio green coloured with marked pleochroism to greenish yellow colour (Plate 7:17). Relief is moderate to high. Most of the grains show the characteristic (brilliant green-purple red) ringed interference colours. It varies from 9.42% to 17.48% and in
frequency 5 to 7 in Surma Sandstones while in the Tipam sandstones show variations from 18.61 to 35.25% and frequency from 6 to 7.

KYANITE:

The mineral occurs as short prismatic, sub-angular, bladed, elongated grains. Cleavage and fracture are distinct. The minerals bear light blue hue. Both opaque and non-opaque inclusions are present (Plate 7:18). Percentage varies from 1.45% to 9.89% and frequency varies from 1 to 5 in Surma while in the Tipam Sandstones it ranges from 2.46% to 7.33% and in frequency scale varies from 3 to 5.

ZOISITE:

Minerals occur as angular to sub-angular; colourless to pale-green. The coloured grains show pleochroism from lighter shades to pistachio green. Relief is moderate to high. Grains show ringed interference colours. In Surma Sandstones, it varies from 1.86% to 5.62% and in frequency 2 to 4. Tipam sandstones shows variation from 1.06% to 1.98% and in frequency from 1 to 2.

STAUROLITE:

It occurs very rarely. The shape of the minerals is angular and sub-rounded; sometimes hackly fractures and irregular boundaries are observed. The mineral bears light pale-brown shade. Few grains indicates the development of hacksaw structure which is a characteristic features of Tertiary sequence.

ANDALUSITE:

The minerals occur as colourless and light pink; prismatic to sub-angular. Inclusion present, which may be sericite
or Kaolinite. Prismatic grains exhibits parallel extinction.

SILLIMANITE :

It occurs impersistantly and are sub-angular, flat, short slender prismatic grains with radiating fibrous (Plate 7:19). Colourless to light grey in colour. Relief is moderate to high and show parallel extinction. Opaque inclusions present. It varies from 0.80% to 4.66% with variation in frequency from 1 to 4 in the Surma sandstones. In the Tipam sandstones its percentage varies from 0.60% to 4.31% and frequency from 1 to 4.

CHLORITE :

Very rarely occurs. It shows pale greenish yellow colour and are elongated, irregular flakes in habit (plate 7:20). Percentage varies from 0.47% to 1.87 and frequency from 1 to 2 in Surma Sandstones. In the Tipam sandstones, it ranges from 0.66% to 1.31% and in frequency from 1 to 1+.

CHLORITOID :

It occurs as flakes, irregular to sub-rounded. Pale greenish brown and olive green in colour. Opaque inclusions present. It varies from 2.31% to 5.62% and in frequency from 3 to 4. In Tipam sandstones it varies between 1.80% to 9.40% and in frequency from 2 to 5.

MUSCOVITE :

It occurs as flakes and most of the grains are colourless, pleochroic in shades of light green and pale reddish brown. Some of the grains show perfect cleavage, shown by perfect lines. It whos straight extinction and low order interference colour.
It shows variations from 1.78 to 5.17% in percentages and 2 to 4 in frequency in the Surma sandstones. In the Tipam Sandstones it varies from 1.20% to 5.42% in percentages and from 2 to 4 in frequency.

BIOTITE:

The minerals are flaky with irregular sub-rounded outline. It shows the colour pale-green and deep-brown and shows weak pleochroism. Minute inclusions present. It varies from 0.54% to 2.83% and in frequency from 1 to 3 in the Surma and in the case of Tipam sandstones it varies from 0.72% to 6.1% and from 1 to 4 in frequency scale.

HORNBLENDE:

Hornblende occurs as short prismatic, flat and irregular shaped grains. The minerals bears pale green and brown colours and exhibits pleochroism (Plate-21). It shows oblique extinction. Grains commonly having opaque inclusions. In the Tipam sandstones it occurs fair abundantly but in the Surma its occurrences is noted very rarely. Percentages in the Tipam sandstones varies from 1.58% to 3.87% and in frequency 2 to 5.

Z.T.R. MATURITY INDEX:

The Z.T.R. maturity index, which defines the mineralogical maturity of the heavy mineral assemblages, is low for the Surma and the Tipam groups of Sandstones (Table-26A and 26B). In case of the Surma Sandstones, it ranges from 21.72% to 30.38% and the average being 25.98%, which indicates low maturity value for the Surma sandstones. In Tipam sandstones, it varies from 13.33% to 43.88%; the average being 26.55% suggesting low maturity value for the sediments.
The ultimate source of a detrital sand grain is the igneous or metamorphic rock in which the grain was originally crystallized. Heavy minerals found to be useful in the provenance study of relatively immature sandstones, because they typically contain the greatest diversity of heavy minerals (Owen, 1987). Heavy mineral provinces, either stratigraphic or geographic, may be defined by the joint occurrence of several diagnostic heavy mineral species (Van Andel, 1959). The heavy mineral assemblage of epidote, garnet, staurolite, chloritoid, chlorite, biotite and hornblende found in the Surma and the Tipam sandstones from the area under study is suggestive of contribution of a part of the sediments from metamorphic rocks and a part from the igneous rocks. Zircon and tourmaline also show much affinity towards metamorphic parentage of the sandstones, though their igneous derivation cannot be ruled out. Blatt et al., (1972), observed that brown and pale brown varieties of tourmaline indicate the exposure to be of metamorphic rocks in the distributive province. Turner and Verhoogen (1962) noted that chloritoid and chlorite are typical epi-zone minerals; staurolite and epidote are characteristic of meso-zone, while biotite and garnet are the typical minerals of kata-zone. Heinrich (1956), Pettijohn (1984), Folk (1974) and Chaudhri and Gill (1981), also observed that the mineral assemblage comprising epidote, garnet staurolite, chloritoid/chlorite and biotite is suggestive of metamorphic provenance. The presence of bladed, angular and colourless Kyanite suggest high grade metamorphic parentage, while the occurrence of anadalusite indicated the presence of low pressure and contact high temperature metamorphic rocks in source area of the Surma and Tipam Groups of sandstones.

Observation leads to infer that the heavy mineral suites of the two Groups of sandstones were derived from the metamorphic rocks associated with pegmatitic veins (Milner 1962; Mirsky 1961). The marker heavy minerals such as epidote,
Zoisite, staurolite, Kyanite, sillimanite, andalusite and hornblende are the index metamorphic minerals. In the Surma and the Tipam sandstones of the area which belongs to the molasse stage, these heavy minerals are found to be present (Sinha & Sastri, 1973, p. 128).

The morphological studies of Zircon favour to draw the conclusion that zircon bearing sediments of the present two groups of sandstones might have been derived from the igneous and metamorphic sources. Similarly, prismatic, angular, brown to black, green and pink coloured tourmalines with inclusions, suggest their derivation from granitic and metamorphic sources (Jt Greensmith, 1984). The round and broken tourmaline grains are the products of abraded detritals of many mixed types. Round shape along with some fragmental grains of tourmaline originated due to abrasion of idiomorphic grains, while transported from source to the site of deposition. Again some fragmental grains became subrounded profitably due to rolling effect of transportation. Heinrich, 1956, suggested that tourmalines also indicates medium grade metamorphic origin.

All these morphological characters of the tourmaline grains indicates that the Surma and the Tipam Groups of sandstones were derived from metamorphic as well as igneous source rocks.

Abundance of opaques indicates igneous source. Presence of minor amount of staurolite and muscovite in the heavy mineral assemblages indicates a metamorphic source.

The low value of 'ZTR' maturity index suggest the immaturity of the two groups of sandstones. Comparatively small percentage of tourmaline and zircon and occurrences of other unstable heavy minerals also indicates compositional immaturity. The low maturity index and unstable heavy minerals indicate short transportation, rapid and intense deformation in the source area and quick deposition of the sediments of the present sandstones in the basin (Hubert, 1962).
High length-breadth ratio of zircon also indicates a non-sedimentary provenance (Poldervarrt, 1955). Zircon, tourmaline-rutile content shows a general decline from the lower formation to upper formation and this is ascribed to the younger age (Hubert, 1962) and their comparatively immature nature.

A high proportion of epidote and garnet, and presence of staurolite, Kyanite and Sillimanite suggest the successive unroffing of deeper seated metamorphosed rocks, showing a higher grade of metamorphism and an increasing intensity of diastrophism in the provenance with decreasing age of the sediments. Folk (1961), indicated that the abundance of garnet and epidote suggest a metamorphic distributive province.

It is observed that unstable minerals are present in the recently deformed and elevated mountain ranges. According to Van Andal (1959), the unstable suites are characteristics of foredeep deposits and the source areas are the Alpine type. In foredeep, mineral assemblage is essentially preserved in the composition inherited from the source area. Unstable minerals present in the sediments indicated pronounced relief and rapid erosion in the source area with rapid burial in the depositional basin.

The authigenic overgrowths in both zircon and tourmaline grains, suggest post-depositional diagenetic changes. Presence of andalusite and hornblende in the two sandstones groups attributed partly to their comparatively unstable nature and partly to the role played by intrastratal solutions.

Sinha and Sastri (1973), while trying to correlate the Tertiary geosynclinal sediments of the Surma valley of Assam and Tripura, concluded that the oldest sediments in the area, which is of Eocene age, yielded very few heavy minerals. Effects of interstratal solution does not seem to have been effectively operative in complete removal of the mineral species. Because, hacksaw termination in
staurolite and tourmaline and overgrowth presumably induced by interstratal solution is displayed by a very few grains only. Therefore, effect of interstratal solution is not very strong for the elimination of mineral species in the present sandstones under study.

The overall studies of heavy minerals suite of the present Surma and the Tipam Groups of sandstones indicate compositional immaturity, intense tectonism and rapid deposition. The sediments were derived from a combined igneous and metamorphic sources of active continental block. The source may be the complex metamorphic basement and granitic intrusive occurring at the central Assam Plateau (Mikir massif), situated towards the north of the present area. The newly uplifted Himalaya including possibly the Mishimi hills, as well as the Naga-Patkai (Eastern Ophiolite Belt) range appear to have been the other sources of the sediments (Ranga Rao, 1983, P. 154).
EXPLANATION OF THE PLATES ::

PLATE 7:1 EU-HEDRAL ZIRCON WITH WELL DEVELOPED CRYSTALLINE FACES (P.L.).

PLATE 7:2 COLOURED ZIRCON (C.N.)

PLATE 7:3 PINK ZIRCON (P.L.)

PLATE 7:4 ELONGATED ZIRCON WITH OPAQUE INCLUSIONS (P.L.).

PLATE 7:5 ZIRCON WITH OVER GROWTH (P.L.).

PLATE 7:6 TWINNED ZIRCON (P.L.).
EXPLANATION OF THE PLATES ::

PLATE 7:7  PRISMATIC DEEP BROWN TOURMALINE WITH OPAQUE INCLUSIONS (P.L.).

PLATE 7:8  GREEN AND GREENISH BLUE TOURMALINE (P.L.).

PLATE 7:9  PRISMATIC PINK TOURMALINE (C.N.).

PLATE 7:10 BLUE TOURMALINE (C.N.).

PLATE 7:11 MICROLITHS OF OPAQUE BODIES AS INCLUSIONS IN TOURMALINE (P.L.).

PLATE 7:12 ROUND TOURMALINE (C.N.).

PLATE 7:13 PYRAMIDAL PINK TOURMALINE WITH OVER GROWTH (P.L.).
EXPLANATION OF THE PLATES ::

PLATE 7:14  RUTILE (P.L.)
PLATE 7:15a  CRystalline garnet (P.L.)
PLATE 7:15b  Well rounded garnet (P.L.)
PLATE 7:16  Over growth in garnet (P.L.)
PLATE 7:17  Epidote with Hackshaw Structure (P.L.)
PLATE 7:18  Kynite (C.N.)
PLATE 7:19  Sillimanite (P.L.)
PLATE 7:20  Chlorite (P.L.)
PLATE 7:21  Hornblende (P.L.)