CHAPTER - 4

TURA SANDSTONE FORMATION

4-1. INTRODUCTION :

The sandstone belonging to the Tura Formation is one of the major mappable rock units. The rock in the field is characterized by its friable nature, fine to medium-grained size and white to light buff colour. Petrographical study is aimed towards the identification of the mineralogical constituents and ultimately classify the sandstones. Detrital quartz grains are studied in detail and their genetic types are volumetrically determined so as to get the clue about the type of the source rock of the sandstones. An attempt is made in differentiating the depositional environments and in portraying the tectonic history of the area of deposition with the help of mutual relationships of the textural parameters. The heavy minerals are also utilized in the determination of the provenances.

4-2. PETROGRAPHY :

4-2.1 Mineralogical Composition

Detail petrographical studies under the transmitted light show: quartz, micaceous minerals (muscovite, biotite and chlorite), feldspar, rock-fragments, miscellaneous grains
(tourmaline, zircon etc.), matrix, and cement, and their volumetric percentages are determined (table IA).

Rock-forming minerals:

Detrital quartz grains in the Tura Sandstone Formation predominate over the others which volumetrically varies from 76.98 to 83.59 per cent (table IA). Petrographically determinable quartz grains range from 0.080 mm. to 0.960 mm. in its longest axis.

The following varieties of quartz types are identified: (1) unstrained or (non-undulatory) quartz, (2) strained or (undulatory) quartz, (3) polycrystalline quartz, and (4) chert (Doty and Hubert, 1962, p.22-23; and Blatt and Christie, 1963, p.560-565). The unstrained quartz percentage in the sandstones of the Tura Sandstone Formation varies from 47.23 to 66.48 per cent, whereas the strained quartz ranges from 11.62 to 26.13 per cent. The unstrained quartz often houses tourmaline, zircon and liquid-gas bubbles, whereas strained quartz bears only liquid-gas bubbles. Presence of inclusions in these varieties of quartz suggest their derivation from extrusive igneous rocks (Conolly, 1965, p.126). Polycrystalline quartz particles are represented by two or more small quartz crystal units of having different optical orientations. Volumetrically, polycrystalline quartz in the sandstones of the Tura Formation varies from 2.45 to 5.62
per cent. These are derived from metaquartzites, and micaceous quartzose gneisses (Doty and Hubert, 1962, p.22-23).

Chert is least abundant amongst the varieties of quartz in this formation which (found to range from 0.59 to 5.62 per cent.

Muscovite, biotite and chlorite represent the mica group. They are well represented in the sandstones of the Tura Formation (Pl. 11 fig. 2 ). This major group of the petrographical component vary from 2.52 to 6.66 per cent. Muscovite is characterized by their flaky habit in the sandstones, having different size fractions. They exhibit a fresh appearance with frayed edges in few samples.

The feldspar group varies from 0.42 to 2.01 per cent throughout the formation. This group includes mainly plagioclase with insignificant amount of microcline.

Rock-fragments:

The detrital fraction often shows meta-quartzite, phyllite and schist fragments. The amounts of rock fragments in the sandstones vary from 0.80 to 4.28 per cent.

Miscellaneous grains:

Represent iron ore, tourmaline and zircon. Volumetrically, miscellaneous grains vary from 0.24 to 1.10 per cent.
Matrix:

Grain smaller than 0.03 mm. in diameter is considered as matrix of the sandstone. Volumetrically, it ranges from 6.17 to 11.24 per cent.

Cement:

The sandstones are in general characterized by the paucity of cements. It is possible to discern the following two types of cementing materials: 1) silica, and 2) iron-oxide. Iron-oxide occurs both as cementing materials and as stains. It predominates over the silica cement. Silica cement occurs mainly as sparry outgrowths in optical continuity with the detrital quartz. The cementing materials in the sandstones range from 0.57 to 2.64 per cent.

4-2.2 Genetic Groups of Quarts:

The quartz types arranged in the genetic groups are found to be as follows:

1) Plutonic quartz: 89.33 to 96.26 per cent
2) Metamorphic quartz: 2.93 to 7.26 per cent
3) Reworked sedimentary quartz: 0.70 to 3.39 per cent
4-2.3 Mineralogical Classification:

The mineralogical composition of the sandstones is plotted in a triangular diagram (Fig. 3 A), after Doty and Hubert (1962, p.32, fig.8). The points fall within the field of micaceous quartzite and orthoquartzite, reflecting its comparatively insignificant amount of feldspar.

4-3. SIZE-FREQUENCY DISTRIBUTION:

Figures 4 A-D show plots of the data of cumulative frequency percentage with phi scale drawn on probability graph paper which provide the information of grain size frequency distribution.

Mean grain-size ($M_g$) of the sandstones of the Tura Formation varies from $1.40 \phi$ (0.37 mm.) to $2.01 \phi$ (0.248 mm.). Standard deviation ($\sigma_\phi$), a measure of sorting, is found to be variable from $0.58 \phi$ to $1.54 \phi$ (average $0.95 \phi$). Skewness and kurtosis values in the sandstones range from $-0.01 \phi$ to $+0.27 \phi$ and from $0.86 \phi$ to $1.61 \phi$, respectively.

The parameters show that the attributes of the sandstones are mostly medium to fine-grained sand which are moderate, moderately well and well sorted. The well sorted samples are mostly a slightly symmetrically skewed and normal to moderately peaked, whereas moderately well sorted samples are slightly skewed and moderately peaked. A very few moderately
sorted samples are negatively skewed and moderately peaked.

Chronologically, the phi-mean size of this formation increases in value towards the top i.e., decreases in microns. Standard deviation as expressed in phi value, increases from the base towards the top of the formation. However, skewness and kurtosis fail to show any trend in variation in the stratigraphical sections (Fig. 5).

4-3.1 Textural Parameters:

4-3.1(1) Relationships of Parameters:

From the mutual relationships of the textural parameters, an attempt is made to decipher the tectonic history of the area and to have an insight on the different environmental conditions of deposition, namely - beach, river, and dune during the time of sedimentation.

Relationship between $\phi M_s$ and $\phi \sigma_1$:

Scatter diagram of $\phi M_s$ versus $\phi \sigma_1$ using whole phi units shows the linear relationship (Fig. 6 A). The phi mean diameter decreases with corresponding to decrease in phi value of the standard deviation. Figure 5 depicts that the phi mean diameter decreases from the base towards the top of the stratigraphical sequence, where it becomes mode-
rate to well sorted.

Inman (1952, p. 128) has pointed out from this parametric relationship that a "V"-shaped pattern is possible to obtain from the statistical analyses of sandstones from different tectonic set up. Most of the scatter points of sandstones fall on the left side of the "V"-shaped arm. This is characteristic of high rate of subsidence of the area of deposition with high tectonic uplift. Few points lie on the right side of the arm as well and suggest high rate of subsidence and low tectonic uplift (Cadigan, 1962, p.142).

The mean diameter ($M_g$) and graphic standard deviation ($G_f$) using whole phi scale, are plotted against each other in a diagram (Fig.7 A), as suggested by Friedman (1961, p.516; 1962, p.738; 1967, p.328). About 70 per cent points fall into the river environment while the rests occupy the allotted areas for the beach (sands) environment. The sandstones of beach environments are well to moderately well sorted and have mean grain-size from 0.50 $\phi$ (0.71 mm.) to 2.01 $\phi$ (0.248 mm.), whereas the values of standard deviation of river environments vary from 0.50 $\phi$ to 1.54 $\phi$ with the mean grain-size from 0.56 $\phi$ (0.67 mm.) to 1.98 $\phi$ (0.253 mm.).

Mean diameter and graphic standard deviation are plotted in a diagram given by Moiola and Weiser (1968, p.52, fig.8) to discriminate between river and dune environments (Fig.8 A). This figure displays that quite a good number of
samples fall within the area allotted for river than dune environments.

Relationship between $\bar{\phi}$ and $\bar{\phi}$ Skt:

The linear relationship between these two parameters shows that the phi mean grain-size increases with the decrease in phi skewness value (Fig. 6 C). Stratigraphical variation, however, shows a gradual increase of the phi skewness with increasing values in the phi mean size from the base towards the top in the section (Fig. 5).

These parameters are used in distinguishing between beach and dune environments. Nearly 10 per cent of sandstones fall in dune sands and the remainders occupy the beach sands (Fig. 9 C). Although Mason and Folk (1958, p.215), and Folk (1966, p.80) have demonstrated that beach sands are generally negatively skewed, but in the present investigation, it is found that nearly 76 per cent of the samples belonging to the beach environments (sands) are positively skewed.

Relationships between $\bar{\phi}$ Skt and $\bar{\phi}$ $\sigma_T$:

This parametric relationship is particularly used in differentiating between beach and river environments (Friedman, 1967, p.357, figs. 5a, 9). All plotted points fall
into the river environment of the diagram (Fig. 7c, 9).

Relationship between $\phi_{M_2}$ and $\phi_{K_G}$:

The linear relationship of these parameters shows that the phi mean size increases with the corresponding decrease of phi kurtosis (Fig. 10a). Stratigraphical succession does not show any tangible relationship between these parameters (Fig. 5).

4-3.1(2) C.M. Pattern:

One percentile (C) and median grain-size (M) in microns, obtained from the mechanical analysis are plotted in a C.M. Pattern diagram (Fig. 11) (Passenga 1957, p. 1954, Fig. 12; 1964, p. 831-838, figs. 1 and 2). The points fall on the pattern V, VIb, and VII of the "Basic C.M. Pattern". Pattern V relates the characteristics of tractive currents which are quite similar to the river deposit. Segment PQ of the tractive pattern shows a deposit formed by a small amount of sediment with the aid of rolling mechanism and segment NO represents here obviously well sorted sediments, transported by rolling process. The area marked by OPQ represents sediments of intermediate grain-size (medium) and are found to be abundant in the Tura Formation. Pattern VIb is parallel with the limiting line C=M, and denotes the features of the turbid-
dity currents. Both patterns V and VIb represent the grains having medium to coarse sizes. Pattern VII is designated as beach pattern. A very few points are also found to scatter near the largest values of C.

4-3.1(3) Textural Classification:

Data obtained from the mechanical analysis show the following textural variations:

<table>
<thead>
<tr>
<th>Material</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>88.35 to 99.15 per cent</td>
</tr>
<tr>
<td>Silt</td>
<td>0.60 to 7.80 per cent</td>
</tr>
<tr>
<td>Clay</td>
<td>0.24 to 3.83 per cent</td>
</tr>
</tbody>
</table>

For the textural classification of the sandstones, the percentages of sand, silt and clay are plotted in a triangular diagram (Fig. 12 A) after Folk (1954, p. 349, Fig. 1). The majority of the points fall in the sand group while others represent muddy sand group.

4-4. HEAVY MINERAL ANALYSIS:

The heavy mineral corps obtained from gravity separation in a media of bromoform (sp.gra. 2.86) are identified optically and counted after mounting in canada balsam. The sandstone of the Tura Formation yield the following heavy minerals: opaque minerals, zircon, tourmaline, staurolite, rutile,
hornblende, epidote, zoisite, chloritoid, and hypersthene. The yield of heavy mineral corps from the sandstone ranges from 0.023 to 0.038 per cent.

4-4.1 Frequency Distribution:

Opaque Minerals

Magnetite, ilmenite, and hematite are grouped together to represent the opaque minerals. Range of opaque minerals is found to be from 54 to 74.12 per cent in the total heavy mineral suit. Ilmenite with partial alteration to leucoxene becomes characteristic amongst the opaque minerals. There are no marked change in frequency distribution of opaque minerals in the stratigraphic sequence throughout the area.

Zircon

Zircon occurs persistently in the sandstones of the Tura Formation. Volumetric distribution of zircon in this formation ranges from 3.69 to 12.02 per cent. Varieties of colour are displayed by zircons. This facilitates to group the zircons in the following orders: (1) colourless to cloudy, (2) light brown, (3) straw-light yellow, and (4) light-pink-orange.

Colourless to cloudy variety sometimes shows a well developed zoning. This variety is derived from acid igneous rocks. The light brown, colourless, stumpy zircons are charac-
The euhedral zircon with sharp pyramids gives light straw yellow colour and frequently contains inclusions of needle-like, colourless, irregular zircon (Pl. 12, Fig. 1). Few rounded grains showing light pink colour appear to be second cycle zircon. This type of zircon is often attributed by the authigenic overgrowth.

Tourmaline

Among the heavy mineral assemblage, tourmaline varies from 3.35 to 12.62 per cent. It occurs usually as prismatic grain. Rounded tourmaline grains are also occasionally met with.

On the basis of colour and inclusion, tourmaline grains are grouped into four types:

1) Brown tourmaline are strongly dichroic as,

\[ \begin{align*}
\alpha &= \text{straw yellow} \\
\gamma &= \text{dark brown} (Z > X)
\end{align*} \]

Mostly, these are prismatic grains having the inclusions of bubbles, air-cavities etc., which elucidate its derivation from granitic rocks (Krynine, 1946, p. 66).

2) The other type of tourmaline with diversified habits like - rounded, euhedral, and subhedral shows dichroism as,
This variety of tourmalines possess inclusions of carbonaceous matters which gives an idea about their derivation from injected metamorphic terranes (Krynine, 1946, p.68). However, pink tourmalines are also derived from acid igneous rocks (Feo-Codecido, 1956, p.994).

3) Another type of tourmaline gives dichroism as,
\[
\begin{align*}
X &= \text{pale pink} \\
Z &= \text{deep pink (Z > X)}.
\end{align*}
\]
This type also contains vacuoles, inclusions of carbonaceous matter and is generally rounded which often shows authigenic overgrowth (Pl. , Fig. ). Tourmaline belonging to this type is derived from reworked sediments (Krynine, 1946, p.71; Feo-Codecido, 1956, p.994; and Pettijohn, 1957, p.513).

4) Blue tourmaline bears cavities and is dichroic with,
\[
\begin{align*}
X &= \text{mauve} \\
Z &= \text{blue (Z > X)}.
\end{align*}
\]
This type of tourmaline points its derivation from pegmatites (Krynine, 1946, p.68; and Feo-Codecido, 1956, p.994).

Staurolite

Staurolite, a stress mineral, varies from 1.07 to 6.36 per cent in the heavy mineral population. Concertina, a
type of staurolite, with pronounced terminations is also occasion­ally seen (Pl. 42, Fig. 2). It gives following pleochroism:

\[ \begin{align*}
X &= \text{yellow (light brown)} \\
Y &= \text{light lemon-yellow} \\
Z &= \text{deep yellow (}Z > X > Y). \\
\end{align*} \]

Otherwise, staurolite displays deep straw-yellow colour.

Occurrence of staurolite indicates the derivation of the sediments from the metamorphic (contact and dynamothermal) rocks (Pé-Codesido, 1956, p. 994).

Rutile

Distribution of rutile in the Tura Formation varies from 0.23 to 1.68 per cent. On the basis of colour two types of rutile, namely - reddish brown and foxy-red, are distinguished. Foxy-red variety predominates over the former. Both the types display the prismatic and euhedral habit.

Hornblende

Hornblende does not occur persistently and goes only up to 0.46 per cent. Generally, it is rod shaped and is pleochroic with,

\[ \begin{align*}
X &= \text{pale green}, \\
Y &= \text{light green}, \\
Z &= \text{dark green (}Z > X > Y). \\
\end{align*} \]
Epidote

In the heavy mineral residue, the frequency of epidote ranges from 0.38 to 2.99 per cent. Most common variety of epidote is subangular in shape and pleochroic with,

\[ X = \text{colourless} \]
\[ Y = \text{pale greenish yellow} \]
\[ Z = \text{pistacoo green (Z > Y > X).} \]

Stations in soisite, a variety of epidote, are in general parallel to the crystallographic C-axis. The average percentage of soisite is 0.69.

Chloritoid

This mineral is persistent throughout the formation and shows the distribution from 1.06 to 17.28 per cent. Chloritoid, a type of the detritus micaceous mineral, is commonly found as platy blue flake. The other variety shows dirty greenish black and indigo-blue colour. With platy habit, chloritoid displays the following pleochroism,

\[ X = \text{light brown} \]
\[ Y = \text{light blue} \]
\[ Z = \text{yellowish green (Z > X > Y).} \]

Hypersthene

The frequency of hypersthene is found to be variable from 0.87 to 1.96 per cent. Grains mostly occur in prismatic
and tabular habit. The mineral generally shows light pink colour and is pleochroic as follows,

- $X =$ pink
- $Y =$ colourless
- $Z =$ light green ($Z > X > Y$).

Heavy minerals of the Tura Formation display moderate yield. The assemblage of heavy minerals consists of fairly abundant chloritoid (micaceous heavy minerals); very common staurolite; fairly common epidote; hypersthene; and rutile. Zoisite is sporadic in occurrence and absent in some samples. Hornblende occurs casually in a very subordinate quantity. Though epidote is present but fails to manifest any sign of variation in the stratigraphic sections. Chloritoid, tourmaline and zircon are universally present in the sediments and show a wide variations in distribution, whereas garnet disappears completely in this formation. Opaque minerals are of nearly 62 per cent (average) of the total yield and give an idea about its prepondarence from the base to the top in all the sections of the formation.

4.4.2 Z.T.R. Maturity Index:

Zircon, tourmaline, and rutile maturity index, a measure for the maturity of sandstone, varies from 62.96 to
84.94 (table 5A), in the Tara Formation. There is a tendency to show higher values of the maturity index at the top of the formation.

4-4.3 Roundness of Zircon, Tourmaline and Rutile:

Visually determined roundness of zircon, tourmaline and rutile grains varies from 0.28 to 0.53, from 0.32 to 0.45, and from 0.36 to 0.45, respectively. However, roundness fails to exhibit any conspicuous zone of concentration from bottom to top of the formation.

4-4.4 Length and Breadth of Zircon and Tourmaline:

Obtained catanae from the plotting of length and breadth for zircon and tourmaline rest on 1:1 line and cross the 1:2 line but fail to touch the 1:5 line. Most of the scatter points of zircon and tourmaline are confined within the 1:1 and 1:2 lines. The catanae of zircon and tourmaline make a wing-like form away from the origin towards the 1:5 line. This characteristic of the catanae is attributed to the water-laid deposits and the populations have diversified shape (Fig. 3) (Smithson, 1939, p. 351, fig. 9).
4-5. SEDIMENTARY STRUCTURES:

Only a few sedimentary structures are observed in the outcrops of the Tura Sandstone Formation. They are Cross-stratification, parting lineation, graded-bedding, and cut and fill.

Cross-stratification

Cross-stratification is the most conspicuous sedimentary structure and has restricted occurrence in the medium to coarse-grained sandstones throughout the formation. Cross-stratified or cross-laminated units vary from micro-cross-lamination (Hamblin, 1961, p.386) to cross-stratified units within the range of 30 cm. (1 foot) to 2½ metres (more than 8 feet) thick. Usually, the foreset strata are separated by bedding planes occupied by clay pebbles which are less than ½ inch thick. Some cross-laminated units are found to have uniform thicknesses. Simple and trough cross-stratification (McKee and Weir, 1953, p.383, fig.2) are very common in the formation (Pl. 4, fig.1).

Parting lineation

It is interesting to observe by a well laminated sandstone which is separated parallel to bedding planes. 'Parting lineation' (McBride and Yeakel, 1963, p.780) exists
where the parting surface involves several adjacent laminations. Laminations are mostly 0.05 mm. (or less than 0.1 mm.) thick, displaying pale brown colour. Parting lineation is more readily recognized due to its high alleviation. Generally, many grains (fine to medium) are parallelly oriented to parting lineation which is characterized by alternation of pale brown and white coloured sandstone layers.

Graded Bedding

Orientation of grains parallel to bedding plane is obvious in the hand specimen. Graded bedding mostly occurs in the sandstones and varies in thickness from 1 inch to 1 foot. It is marked by a gradation in grain-size which appears to exist between coarse and fine. It is observed in outcrops of sandstones that grain size diminishes upward from the base to the top of the unit (Pl. 3, fig. 2). Some outcrops exhibit fine grains distributed throughout in the sandstones.

Cut-and-fill

Cut-and-fill structures are usually associated with medium-scale cross-stratification which are apparently developed in the basal massive sandstone. Wavy laminae are identified in medium-to-coarse grained sandstone. Interpretation of their origin is more or less similar to that outlined by Sanders (1960, p.412). They are in general trough-shaped.
4-6. INTERPRETATION:

Data obtained from the laboratory and field investigation throw light upon the provenance, depositional environment, and cementation of the sandstones.

4-6.1 Provenance:

Unstrained and strained quartz, representing the plutonic type, house inclusion of tourmaline, zircon and liquid-gas bubbles. As amongst these two types of quartz, unstrained quartz is more common than the strained quartz. It is inferred that these are derived from the igneous rocks (Conolly 1968, p. 126). Polycrystalline quartz is derived from metamorphic rocks such as metaquartzite and micaeous gneisses. Occurrence of chert indicate a sedimentary origin and probably has undergone more than one cycle of erosion and transportation. Comparative preponderance of mica group of mineral further postulates partial derivation of the materials from the metamorphic terrain. Heavy minerals like hornblende, rutile, hypersthene, pink and pale brown variety of tourmaline are derived from the igneous rocks. Blue tourmaline is apparently supplied to the sediments from the pegmatites. A subordinate amount of materials were also carried from the low to medium grade metamorphic rocks, as pointed out by heavy mineral like chloritoid and staurolite. The Z.T.R. maturity index aptly show the effect
of more winnowing of the sediments during the last phase of deposition. Consequently, at the top of the formation, the sediments became more mature (p. 81). The source rocks of mineral association of the Tura Sandstone Formation are diagrammatically sketched (Fig. A).

4-6.2 Depositional Environment:

Size-frequency distribution, relationship of the parameters and C.M. pattern are the most useful indicators for the detection of the depositional environments. The sediments accumulated in the form of beach on the shelf which were traversed by the rivers. Part of the materials from the beach were sorted and formed dune in small quantity (p. 72). Nevertheless, the dominant depositional environment was favourable for the river deposition. The relationship between $M_2$ and $\sigma_x$ shows clearly that the depositional site was subsiding rapidly with high and low tectonic uplift (p. 71). The C.M. pattern also supports the idea of the contention of dominant river and subordinate beach depositional environment (p. 73). Though tractive current played a dominant role, turbidity current was also in existence during the transportation of the sediments by water.

The horizontal lamination, localized nature of cross-bedding and graded bedding allude that there was periodic influxes of detrital material in the depositional site.
4-6.3 Cementation:

The sandstones are very poorly cemented. Iron-oxide occurs cementing materials in the intergranular spaces and as stain upon the grains. This cementing material is with all probability carried to the depositional site in dissolve condition by the water from the land mass. A few quartz grains possess authigenic cementing materials. It is most probable that authigenic cementing materials were formed under the conditions of enhanced temperature and pressure condition during and/or after the depositions.
Fig. A. Diagrammatic sketch of source terrains of mineral association of the Tura Sandstone Formation.