CHAPTER II

LITHOLOGIC AND SEDIMENTARY CHARACTERS

During the last decade or so lithologic and sedimentary characters of the Lower Gondwana rocks have been studied in greater detail in the Damodar Valley coalfields of Bihar and Bengal (Dasgupta, 1956; Mehta and Murthy, 1957; Banerjee, 1960; Srivastava, 1961; Niyogi, 1961, 1966; Niyogi and Sanyal, 1962; Israili, 1967; Rizvi, 1970), Godavri coalfields of Andhra Pradesh (Sengupta, 1966, 1970), and in a few other coalfields (Rao, 1957; Ghosh and Basu, 1967; Rao, et al., 1967; Casshyap, 1970; Casshyap and Jain, 1970). The Gondwana rocks of the Pench Valley coalfield have not yet been examined comprehensively from this point of view. Among the early workers, noteworthy is Cyril S. Fox (1931, 1934) who gave a fairly elaborate account of the lithology of these rocks in the Pench Valley coalfield. Recently Shukla (1968) and Shukla and Rai (1970) studied sedimentary properties of the Gondwana rocks in the neighbouring Kanhan Valley coalfield. However, most of the previous workers described the lithology and sedimentary characters of the Gondwana rocks rather subjectively. Indeed lithologic types, lithologic association and primary depositional features of a sedimentary sequence provide evidence of utmost genetic significance (Krynine, 1948; Krumbein and Sloss, 1963; Visher, 1965; Potter, 1967).

The present study describes at length the lithologic and sedimentary
characters of the three formations, namely, Talchir, Barakar and Motur separately as follows: (1) Lithologic characters and lithologic association, (2) Sedimentary cycles and (3) Sedimentary structures.

1.0 LITHOLOGIC CHARACTERS AND LITHOLOGIC ASSOCIATION

This study is based on a systematic examination of lithologic units encountered in the course of geological mapping. Apparently all the three Lower Gondwana formations of the study area are characterised by a well marked lithologic heterogeneity. The associated rock types, distinctive for each formation, occur in a variable manner and in variable abundance. Rock sections exposed at any one locality seldom exceed a few meters in vertical thickness. Consequently, in order to explore the lithologic variation laterally and vertically, traverses were undertaken at short intervals across the structural strike of the strata, and constituent lithologic units met with were examined, measured and mapped, if possible.

1.10 Talchir Formation

The mappable units of the Talchir formation, recognised in the western part of the study area only and referred to earlier, are shown in Fig. 2 (cover pocket) and listed in Table 3. Their lithologic association from the base to the top and the lateral variation are shown diagrammatically in the measured sections in Fig. 5. Also included in this figure is a stratigraphic section of the Talchir rocks exposed as a narrow faulted patch near the eastern boundary of the study area. No attempt is made to
Fig. 5 Stratigraphic sections across the Talchir Formation showing lithologic association and cyclic units in the western (A, B & C) and eastern (D) parts; A. Chatua-Hinautiia Section; B. Budhvara-Naulakhapa Section; C. Chatua Bhadri Section
correlate the lithologic units of the sequence in this patch with those of the eastern part. Salient sedimentary features within each lithologic unit are appropriately shown in the figure.

The rock assemblage of the Talchir formation, predominantly olive green in colour, can be conveniently subdivided into three broad lithologic groups: (1) diamictite units A, B and C, and a variety of lithologic inclusions occurring therein; (2) finer clastic assemblage associated with diamictite units and (3) conglomeratic transitional sequence of unit D. Table 4 records the approximate percentage (by volume) of dominant lithologic types of the Talchir formation.

1.110 Diamictite Units

The three diamictite units which on the average constitute about 52 per cent of the available Talchir strata are well developed and laterally persistent in the study area showing minor variation in thickness. The minimum average thickness is about 32 m for the lower Unit A, 37 m for middle Unit B and 28 m for the upper Unit C. The contacts of the diamictite units with the associated strata are by and large sharp and gradational with the exception of the upper contact of diamictite unit B which is grossly uneven. The diamictite units are uniformly polymictic and poorly sorted wherein pebbles, cobbles and boulders are sparsely distributed in a tough clayey to sandy and calcareous matrix.
TABLE - 4  APPROXIMATE PERCENTAGE (BY VOLUME) OF LITHOLOGIC TYPES IN THE LOWER GONDWANA FORMATIONS

<table>
<thead>
<tr>
<th>Formation</th>
<th>Diamictite</th>
<th>Conglomerate</th>
<th>Sandstone</th>
<th>Interbedded sandstone and shale</th>
<th>Shale/Clay</th>
<th>Coal and carboneous shale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motur</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit B</td>
<td>-</td>
<td>40</td>
<td>55</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Unit A</td>
<td>-</td>
<td>0.5</td>
<td>30</td>
<td>-</td>
<td>70</td>
<td>-</td>
</tr>
<tr>
<td>Barakar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Talchir</td>
<td>52</td>
<td>0.5</td>
<td>15</td>
<td>11</td>
<td>21</td>
<td>-</td>
</tr>
</tbody>
</table>
1.111 Clast Assemblage

Lithologically, the three diamicrites cannot be differentiated either on the basis of size of clasts and their lithology or clast roundness, their shape and sphericity.

By and large pebbles exceed cobbles and boulders in these diamicrites. Among pebbles noteworthy and widespread are those ranging in size from 8 to 64 mm, while cobbles of 64 to 128 mm size are common than larger ones. Boulders are relatively less common in each outcrop and seldom exceed a meter in diameter. The largest boulder, that of pink porphyritic granite, measuring about 4 m across, occurs in lower diamicrite Unit A in a nala about 2 km southwest of Budhvara.

Percentage (by volume) of embedded clasts in the diamicrite units was determined in several outcrops by following the method used by Casshyap (1969) elsewhere. Commonly clasts are distributed in variable proportion from outcrop to outcrop irrespective of the diamicrite unit, constituting on the average about 10 to 22 per cent of the rock. Lithology was recorded randomly for about 100 clasts in each outcrop. Table 5 includes the composition of 1281 clasts counted in 13 outcrops distributed in the three diamicrite units including that of the eastern part. In each diamicrite unit embedded clasts are represented in variable proportion by variety of igneous, sedimentary and metamorphic rocks. Whereas igneous and metamorphic clasts occur in about the same proportion (55 to 75 per cent) in all the diamicrite units, clasts of sedimentary rocks...
| Diamictite Units | Exposure No. | Quartzose | Pink Porphyritic granite | Basic igneous rock | Granite gneiss | Argillite phyllite & Schist | Quartzite | Banded hematite quartzite | Sandstone | Limestone Shale |
|------------------|--------------|-----------|-------------------------|-------------------|---------------|-----------------------------|-----------|-------------------------|-----------|
| **Diamictite C** | I            | 2.0       | 30                      | 5.0               | 24.0          | 3.0                         | 8.0       | 3.0                     | 5.0       | 12.0 7.0         |
|                  | II           | 8.0       | 45                      | 10.0              | 15.0          | 1.0                         | 5.0       | -                       | 8.0       | 6.0   2.0        |
|                  | III          | 8.0       | 34                      | 2.0               | 28.5          | 2.0                         | 4.0       | 1.0                     | 4.0       | 15.0 1.1        |
|                  | IV           | 3.4       | 36                      | 1.6               | 32.0          | 5.0                         | 10.0      | 3.5                     | 1.6       | 5.0   0.4        |
| **Diamictite B** | I            | 5.0       | 28                      | 1.0               | 30.0          | 1.0                         | 4.5       | 1.0                     | 7.0       | 18.0 4.0        |
|                  | II           | 5.0       | 39                      | 1.0               | 30.5          | 4.0                         | 1.0       | -                       | 4.0       | 13.0 1.5        |
|                  | III          | 10.0      | 35                      | 5.0               | 32.0          | 3.0                         | 1.0       | -                       | 1.6       | 12.0 0.4        |
| **Diamictite A** | I            | 3.5       | 29                      | 1.0               | 24.0          | 1.5                         | 3.0       | -                       | 8.0       | 28.0 2.0        |
|                  | II           | 8.0       | 30                      | 2.0               | 15.0          | 1.7                         | 3.0       | 0.3                     | 11.0      | 32.0 6.0        |
|                  | III          | 6.0       | 22                      | 2.0               | 44.0          | 3.5                         | 15.0      | 1.5                     | 3.1       | - 1.9           |
|                  | IV           | 15.0      | 50                      | 9.0               | 18.0          | 0.5                         | 6.0       | -                       | 0.2       | 0.8 0.2         |
|                  | V            | 12.0      | 35                      | 5.0               | 18.0          | 1.7                         | 9.0       | 1.0                     | 2.0       | 16.0 -          |
|                  | VI           | 7.0       | 30                      | 8.0               | 30.0          | 1.5                         | 7.0       | 0.5                     | -         | 15.0 1.0        |
| **Eastern Part** | I            | 6.0       | 40                      | 2.0               | 30.0          | 2.0                         | 7.0       | -                       | 1.5       | 10.0 0.5        |
|                  | II           | 12.0      | 40                      | 6.5               | 35.0          | 1.0                         | 2.5       | 0.5                     | 2.5       | -                |

For location please refer to Figure 2 (Cover pocket).
are apparently more common in the lower (average 30 per cent) than middle (average 18 per cent) and upper (average 14 per cent) diamictite (Fig. 6). Among the specific rock types represented by clasts are porphyritic granite (22 to 50 per cent), granite gneiss (15 to 44 per cent), basic igneous rock (5 to 9 per cent), red sandstone (less than 1 to 11 per cent), banded hematite quartzite (less than 1 to 11 per cent), quartzose fragment (2 to 15 per cent), limestone (5 to 32 per cent) and shale (less than 1 to 11 per cent). By and large the polymictic composition in about the same proportion persists in clasts of different sizes.

Roundness of clasts taken out of the outcrop was estimated visually from chart developed by Krumbein (1941), and for each diamictite it appears to be independent of the clast composition - a feature observed by several workers elsewhere (Frakes and Crowell, 1967, p. 43; Lindsay, 1970, p. 1158). Generally speaking, boulder greater than about 0.5 m, which are mostly of porphyritic granite, are well rounded (roundness 0.8-0.9), but smaller clasts from large cobbles down to fine pebbles, demonstrate a wide variation in roundness from angular and subangular to subrounded and rounded.

Shape of clasts was determined following the method outlined by Sneed and Folk (1958, p. 123). Based on appropriate measurements of long, short and intermediate axis of clasts 125 values were computed (Appendix I). Preliminary plots separately for each diamictite unit ruled out significant variation in the shape of clasts; nor was the
Fig. 6 Percentage variation of igneous, sedimentary, and metamorphic clasts in the diamictite units and transitional zone of the Talchir formation.
variation conspicuous with respect of their respective lithology. Fig. 7A shows a composite shape plot for igneous sedimentary and metamorphic clasts of all the three diamictite units. Among the more commonly occurring shapes of clasts were "bladed" (26 per cent); 'compact bladed' (22 per cent); 'elongated' (12 per cent) followed by 'compact platy' (10 per cent) and so on. Smaller clasts ranging in size from 2 to 12 cm have roughly triangular or pentagonal 'flat-iron' shapes with rounded smooth edges (Plate 2 A ). These clasts are always dominated by a conspicuous basal facet. Quartzite, basic igneous rock and a few limestone clasts are particularly faceted, and bear subparallel striations (Plate 2 B).

Fractures are particularly common in larger clasts, irrespective of lithology (Plate 3 A ). In most of the cases fractures tend to orient parallel to the long axes of clasts and do not extend into the surrounding diamictite matrix. However, interestingly, in many cases matrix of the diamictite units is found to fill in the fractures. Fractured and broken clasts have been reported from diamictite deposits and ascribed, more plausibly, to freezing and thawing (Harland, et al., 1966, p.246; Lindsey, 1969, p.1690).

Following Folk and Sneed (1958, fig. 2) sphericity of clasts was obtained by interpolating the points between "isosphericity" contours. Histogram in Fig. 7B illustrates for each recorded sphericity class corresponding percentage of clasts. The distribution is clearly unimodal with about 35 per cent clasts lying in
the dominant (modal) sphericity class of 0.7-0.8. The rests of the clasts exhibit sphericity varying from 0.4 to 0.9.

1.112 Massive Diamictite

Structurally two types of diamictites may be recognised in the study area (1) massive diamictite (2) partially stratified diamictite.

Of the three diamictite units recognised in the western part of the study area, the lower Unit A, middle and upper parts of Unit B and lower and middle parts of Unit C are apparently massive and non-stratified (Plate 3 B). The undifferentiated diamictite unit of the eastern part of the study area is hard, compact and apparently massive. Embedded clasts comprising on the average 14 to 18 per cent (by volume) of the rock, are generally sparsely scattered in the massive diamictites. Although massive, these diamictites contain inclusions of sandstones in various shapes, slumped and twisted and as thin lense.

Slumped and twisted bodies of sandstone occur frequently in non-stratified and massive diamictites (Plate 3C & 4A). Usually these are small bodies varying in size from a meter to about 2 m, and are twisted and deformed into a variety of shapes. There may either be a single twisted body of sandstone in the diamictite (Plate 3C) or may be more than one, some of which sharply bent at one end forming a "hook" shaped structure (Fig. 8); others resemble 'slump over fold' structure (Crowell, 1957, p. 1000). Apparently the host diamictite is not appreciably disturbed or deformed anywhere along the contact of sandstone inclusions or around. Large sandstone bodies are, however,
EXPLANATION OF PLATE 2

A: Facetted flat-iron shaped pebbles from the diamictite units of the Talchir formation showing triangular, quadrangular and petagonal outlines.

B: Limestone clast of the diamictite unit showing subparallel striations.
less deformed and may occur as isolated lens in diamicrites (Plate 4 B ). Some large sandstone bodies, relatively less common, occur in thin lenses (Plate 4 C ) or appear as a triangular body in cross-section (Plate 4 C ). Also present, locally, in massive diamicrites are thin lenses of conglomerate. Both sandstone and conglomeratic lenses vary in thickness from less than about 10 cm to about 2 m and laterally pinch-out within a couple of meters. They are generally green in colour, medium to fine grained and exhibit faint bedding or cross-bedding (Plate 4 C ). Their lower and upper contacts vary from straight to uneven. The other sandstone inclusion appearing as triangular body in cross-section with apex of the triangle tapering downwards (Plate 4 C ), seldom exceed 10 m in length and zero to 5 m in thickness. These are medium to coarse grained and apparently massive; their lower contact is more sharp than upper contact. In some cases the overlying diamicrite material is found intruding into the sandstone bodies.

Slumped, twisted and deformed sandstone bodies, similar to those referred to above, have been abundantly reported elsewhere from diamicrite deposits attributed to subaqueous mass movement (Crowell, 1957, 1964; Crowell and Frakes, 1971a, 1971b; Dott, 1961; Lindsay, 1966; Frakes and Crowell, 1967, 1969; Frakes, et al., 1967) as well as from those considered to be glacial in origin, namely, tills or tillites (Pettijohn, 1957a; Lahee, 1952; Frakes and Crowell, 1969, p. 1030). Likewise, sandstone or conglomeratic lenses in diamicrites have recently been described by several workers (Frakes and Crowell, 1967, p. 47; Frakes,
EXPLANATION OF PLATE 3

A: A gaping fracture splitting a large granitic boulder embedded in diamictite Unit A.
   Creek cutting, approximately 3 km west-southwest of Hinautia village.

B: A typical outcrop of massive diamictite Unit B. Large and small clasts are sparsely dispersed in muddy matrix.
   Creek cutting, approximately 5 km southwest of Sukri village.

C: A small twisted sand body embedded in massive diamictite of the middle part of Unit B.
   Creek cutting, approximately 4 km south of Sukri village.
et al., 1968, p. 7; Casshyap, 1969; Lindsay, 1970, p. 1153) and interpreted as "subglacial eskers". The triangular sandstone bodies in diamictites have been described as 'wedge forms' (Frakes, et al., 1968, p. 8; Lindsay, 1970, p. 1153) and interpreted as sand filled open fissures in "frozentill".

In the eastern part of the study area, the massive diamictite locally includes a thin sliver of sandstone lense about 2 cm thick and outcropping laterally for about half a meter. It is medium grained and exhibits on the exposed upper surface well-developed parallel grooves (Plate 5 A). There is apparently no evidence of tectonic displacement, which otherwise may have accommodated for the grooves. In all probability the structure is a primary feature and closely resembles the 'sandstone laminae' described recently from Palaeozoic glacial rocks of Central Transantarctic Mountains (Lindsay, 1970, p. 1155).

1.113 Stratified Diamictite

Talchir diamictites in the study area exhibit stratification at least at two levels (1) in the lower part of middle diamictite (Unit B); (2) locally in the upper part of middle (Unit B) and upper (Unit C) diamictite. In these rocks stratification commonly develops due to interbedding of thin sandstone and silty shale (Plate 5 B). In places, thin sandstone interbeds in the lower part show soft sediment deformation on a minor scale as also exhibit 'slump' structures (Fig. 9). Occasionally, the diamictite Unit B in the middle part includes at least three interbeds of sandstone alternating with thin
EXPLANATION OF PLATE 4

A : A twisted and hook like lens of a sandstone in the diamictite Unit B.
Creek cutting, approximately 2 km southwest of Khairwani village.

B : Conglomeratic sandstone lenses in the massive diamictite Unit A.
Creek cutting, approximately 3 km southwest of Hinautia village.

C : A triangular sand body and a channel sandstone in the massive diamictite Unit C.
Creek cutting, approximately 5 km southwest of Sukri village.
diamictites. The interbedded sandstone varies in thickness from 10 cm to 15 cm and pinches out laterally within a distance of a couple of meters. It is earthy white to greenish in colour, muddy and exhibits on upper bedding surface asymmetrical to interfering (Linguoid) ripple marks, as also, in the case of uppermost interbed, well developed unidirectional coarse striations and miniature grooves (Plate 5C). These striations and grooves, some of which are about 8 cm wide and 2 cm deep occur all over the available surface of the sandstone (about 3 sq m). Interbedded in the striated sandstone at the far end of a groove is a small cobble (Plate 5D). Such type of sandstone interbeds closely resemble those interpreted as 'soft-sediment Pavement' by Lindsay (1970, p. 1161).

Although embedded clasts in stratified diamictites seldom exceed 10 per cent of the total rock, locally there are patches of 4 sq m or less in which the embedded clasts are greater in number and closely spaced forming "grouped clasts" (Plate 6A) (Frakes and Crowell, 1967, p. 44). In some places, however, stratified diamictite, like massive diamictites, includes thin interbeds of pebble conglomerate. Among other features of stratified diamictite are spherical nodules of arenaceous limestone which occur in variable number embedded on the upper surface of Unit B. The nodules vary from about 5 to 20 cm in diameter. They are generally sparsely distributed but in some outcrops they occur in a large number (Plate 6B). Small pebbles similar to those in the host diamictite occasionally occur included in the nodules. On cutting and polishing,
Fig. 8 A field sketch showing twisted and fractured sandstone body in massive diamictite unit of the eastern part. Locality: 3 km southeast of Parasia in a nala cutting.
the small-scale cross-bedding of the host rock was found to continue into the adjoining calcareous nodule.

1.120 Finer Clastic Assemblage Associated with Diamictites

Each diamictite unit is overlain by a well developed mapable assemblage of finer clastics comprising mainly sandstone and shale (Fig. 5). Among the dominant lithologies which constitute this assemblage more important are (1) fine to medium sandstone; (2) interbedded sequence of sandstone and shale; and (3) shale.

1.121 Sandstone

Well developed sandstone units in the Talchir formation occur at four stratigraphic levels succeeding each diamictite unit, and have been designated as A1, A3, B1 and C1 (Fig. 5 and Table 3). On the average sandstone forms about 15 per cent of the bulk of Talchir assemblage.

The lower sandstone (subunit A1) occurring above the lower most diamictite A is green to yellowish in colour. It is by and large fine grained, compact and horizontally bedded, and is about 30 m thick near the western side but its thickness decreases to about 6 m when followed eastward. Its lower contact with the diamictite is sharp to slightly wavy. At a few places the upper surface of this sandstone exhibits well developed ripple marks which are symmetrical to slightly asymmetrical.

The second sandstone designated as subunit A3 occurs just below the stratified diamictite (Unit B) and is about 6 m thick. The lower contact of this sandstone with the interbedded sandstone - shale sequence
EXPLANATION OF PLATE 5

A : Grooved sandstone laminae within the massive diamictite Unit of the eastern part of the study area.
Creek cutting, approximately 1 km northeast of Khirsadah Railway Station.

B : A typical outcrop of stratified diamictite (Unit B) showing thin discontinuous intercalations of clay and fine sandstone. Pebbles cobbles are sparsely distributed.
Creek cutting, approximately 2 km south-southwest of Khairwani village.

C : Thin sandstone interbeds in the diamictite Unit B. Each sandstone bed exhibits linguoid and asymmetrical straight ripples, and the uppermost bed in the foreground also shows unidirectional small grooves resembling soft sediment pavement.
Bhangi stream, approximately 200 m northeast of Chatua village.

D : Enlarged view of the grooved and rippled sandstone laminae showing a cobble mould (near the head of the hammer and an embedded cobble in the foreground, as also the underlying diamictite. The grooves are oriented northwest-southwest.
and the upper contact with the stratified diamictite are more or less gradational. This sandstone is slightly calcareous, fine grained and massive, though at places shows isolated sets of small-scale cross bedding.

The third sandstone subunit (B3) which varies in thickness from 3 to 6 m separates the underlying diamictite B and the overlaying massive diamictite C (Fig. 5; Plate 6c). This sandstone is dark green and apparently massive. In comparison to two previous sandstones it is a bit coarser grained. Strikingly, the lower surface of this sandstone at several places is highly uneven and irregular; the underlying diamictite seems to have been pushed upwards across the sandstone bed as well as into smaller fracture planes near the irregular lower surface (Plate 6c). The "pushing upward" or "intruding" phenomenon across the sandstone has taken place at close intervals mostly along planes which seem to be fairly regularly aligned northwest-southeast. The structure is well displayed all along the northern embankment of Bhangi rivulet (Fig. 2, cover pocket), for a distance of about 100 m, so much so that diamictite unit in the lower part and underlying sandstone appear to be dismembered into irregular blocks of different dimensions. The feature may be close to, if not, similar to, 'ball-and-pillow' structure in subaqueous deposits (Potter and Pettijohn, 1963, p.148).

The fourth prominent sandstone designated here as subunit C1 is exposed above the massive diamictite unit C and is traceable laterally all along the limits of the western part of the area. The lower contact of this
Fig. 9 Polished specimen from lower part of diamicite Unit B showing slump structure
subunit with the diamictite is sharp whereas the upper contact with shale is gradational. This sandstone is olive green, fine grained to clayey, and varies in thickness from 0 to 15 m. It exhibits occasionally isolated sets of small-scale cross-bedding, but some coarse grained varieties exhibit isolated sets of large-scale cross-bedding. Enclosed in this unit at places are isolated pebbles, cobbles and boulders.

1.22 Inter-bedded Sequence

There are at least two assemblages (subunits A2 and C2) in the western part of the study area which can be designated as inter-bedded sequence of sandstone and shale. Associated with sandstone subunits referred to above, they occur stratigraphically in the middle and upper parts of the Talchir formation (Fig. 5), and constitute about 11 per cent of the bulk of the Talchir strata (Table 4).

The first sequence occurring above the sandstone A1 represents moderately thick assemblage (12 m) of alternating green shale and fine grained gray sandstone (Plate 7 A ). Thickness of sandstone and shale interbeds is variable ranging from a few cm to about 25 cm. The second interbedded sequence occurring in the upper part of the Talchir formation represents an assemblage of reddish shale and gray fine sandstone.

Thickness of sandstone interbeds varies from a few centimeter to about 10 cm some exhibiting asymmetrical ripple marks on as many as five successive bedding planes. The lower and upper contacts of both the units are gradational.
EXPLANATION OF PLATE 6

A: Grouped clasts in the lower part of stratified diamictite Unit B. Creek cutting, about 1 km northwest of Khajri village.

B: Small spherical calcareous nodules in the diamictite Unit C. Creek cutting, approximately 2 km south-southeast of Budhwara village.

C: Outcrop showing dismembered sandstone subunit (B₁) with uneven and irregular lower contact. The diamictite unit below forces its way into large and small fractures of the sandstone.
1.123 Shale

This rock type occurs as a well developed lithologic subunit (C3) underneath the 'conglomeratic transitional zone' (Unit D) (Fig. 5) and constitutes about 21 per cent of the total strata. It is the typical "Talchir Shale" and as elsewhere in the Peninsular Gondwana basins, it weathers into small needle-like fragments. The Talchir shale, hence, is often described as 'needle' shale (Krishnan, 1960, 1968). This shale is typically green in colour though locally it is red. It is generally calcareous, including at places thin lenses of marl. Isolated pebbles, cobbles and boulders occasionally showing scratches or subparallel striations, may occur in the shale as 'lonestones' which may well be interpreted as 'dropstones' inasmuch as they occasionally deform the underlying laminae (Plate 7B).

1.13 Conglomeratic Transitional Zone

This lithologic sequence designated here as Unit D, forms the uppermost subdivision of the Talchir formation in the study area, and is well developed in a creek cutting south of village Nazarpur. Its lower contact with the underlying green shale is clearly uneven and possibly erosional (Plate 7C). The lithologic sequence of this unit, shown in Fig. 5, comprises from the base upward: pebbly to cobbly polymictic conglomerate, coarse to medium sandstone, and interbedded sequence of sandstone, shale and carbonaceous shale. Pebbly to cobbly conglomerate is about 10 m thick, of which lower 7 m is mainly conglomeratic which grades upward into coarse sandstone. Clasts in this unit make up about 40 to 50 per cent of the total rock. However, proportion of igneous
EXPLANATION OF PLATE 7

A: Interbedded sequence of fine sandstone and green shale (subunit A3) of the Talchir formation.
Creek cutting, approximately 3 km south-southwest of Khairwani village.

B: Laminated Talchir shale including a large "drop stone".
Creek cutting, 100 m north of Bhadri village.

C: Uneven lower contact of the conglomeratic sandstone of the uppermost transitional zone of the Talchir formation (Unit D) with the underlying green shales.
Creek cutting, approximately 3 km south of Nazarour village.

D: Green shale of Unit D of the Talchir formation containing a large isolated boulder.
Creek cutting, approximately 5 km southwest of Ambara.
and metamorphic (mainly granite gneiss and quartzite) clasts ranges between 44 to 66 per cent and 35 to 45 per cent respectively (Fig. 6), whereas sedimentary clasts make up a very small proportion (1 to 11 per cent). Although shape and sphericity of these clasts is more or less similar to those of the underlying diamictite units (Figs. 10A and B), they are slightly better rounded (roundness 0.5-0.6) in this unit. Both conglomerate and coarse sandstone are earthy yellow in colour and profusely cross-bedded, and both contain reworked underlying material including fragments of green shale. Carbonised wood fragments frequently occur in the associated coarse sandstone.

The conglomerate-sandstone assemblage is succeeded upward by interbedded sequence of green shale and sandstone which is about 40 m thick, as also laterally continuous. 'Lonestones' and (or) 'dropstones' showing faint striations are, however, not uncommon in the interbedded green shale and are mostly of pebble size, but at one place near the top of this unit the embedded clast is a boulder measuring about 60x90 cm (Plate 70). In the upper part, near the contact with the Barakar formation, the interbedded sequence includes some lenses of carbonaceous shale; the associated sandstone is relatively fine grained.

1.20 **Barakar Formation**

The Barakar formation in the study area, exposed in discontinuous linear patches, occupies mainly the southern half of the study area (Fig. 2, cover pocket). Distribution of lithologic units through the Barakar formation is more elaborately known from the available bore hole data
cTENOUS
•
seOlf^NTORY
+ MEIAktORphlC

L-S
B
^30
U
3
I-
E
(1
5
5
5
5
5
5
5

ELONGATED

S/L

PLATY

L-1

L-S

Compact
1.0

IGNEOUS
SEDIMENTARY
METAMORPHIC

A

B

0

40

30

20

10

Frequency

Percent

Sphericity class

Triangular plot showing shape of clasts of igneous, sedimentary, and metamorphic origin embedded in conglomeratic unit of the transitional zone. D B: Histograms showing frequency distribution of clast sphericity for samples of transitional zone.
illustrated as columnar diagrams (Fig. 11B). However, for a comparative examination and other details, several stratigraphic sections were measured along traverses made across the strike of the strata and are shown diagramatically in Fig. 11A. As elsewhere, the Barakar formation in the study area consists of interbedded assemblage comprising coarse to medium sandstone, fine sandstone, siltstone, carbonaceous shale and coal. The interbedded sequence made up of one or more of the above lithologic units occurs repeatedly throughout the formation from the base to the top. The approximate percentage (by volume) of prominent lithologic types of the Barakar formation are recorded in Table 4.

Using thickness data recorded in bore-hole and stratigraphic sections, ratio values of sandstone/shale (sand-shale ratio) and sandstone and shale/coal (clastic ratio) were computed and the results are listed in Table 6. Sand-shale ratio generally varies from 3.5 to 9.6 evidently implying that the bulk of the available Barakar assemblage in the study area is made up of sandstone followed by siltstone and shale. The Barakar rocks of this area are known to be poor in coal (Fox, 1934, p.14) as is evident from columnar diagrams (Fig. 11A and B) as also from clastic ratio which in places is as high as 141. For the purpose of lithologic description the Barakar formation has been subdivided into (1) Coarse to medium sandstone (2) fine sandstone (3) siltstone, and (4) carbonaceous shale and coal.

1.21 Coarse to Medium Sandstone

This variety of the sandstone is by far the most abundant and widely
BARAKAR FORMATION

(A) Based on measured stratigraphic section

(B) Based on borehole data

LEGEND

- **LARGE SCALE CROSS-BEDDING**
- **SMALL SCALE CROSS-BEDDING**
- **PARALLEL LAMINATION**
- **COAL**
- **CARBONACEOUS SILTSTONE AND SHALE**
- **SILTSTONE AND SHALE**
- **SANDSTONE**
- **VERY COARSE SANDSTONE**
<table>
<thead>
<tr>
<th>Represented Data</th>
<th>Percentage of Sandstone</th>
<th>Percentage of Shale</th>
<th>Percentage of Shaly Coal</th>
<th>Total</th>
<th>Sandstone/Shale ratio</th>
<th>Clastic Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Based on measured stratigraphic sections</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*1</td>
<td>72.7</td>
<td>13.0</td>
<td>14.1</td>
<td>99.8</td>
<td>5.5</td>
<td>2.6</td>
</tr>
<tr>
<td>*2</td>
<td>71.2</td>
<td>21.9</td>
<td>6.8</td>
<td>99.9</td>
<td>3.2</td>
<td>2.4</td>
</tr>
<tr>
<td>*3</td>
<td>92.8</td>
<td>0.7</td>
<td>6.3</td>
<td>99.8</td>
<td>132.5</td>
<td>13.2</td>
</tr>
<tr>
<td>*4</td>
<td>39.0</td>
<td>-</td>
<td>60.9</td>
<td>99.9</td>
<td>39.0</td>
<td>0.64</td>
</tr>
<tr>
<td>Based on borehole records</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*1</td>
<td>66.6</td>
<td>19.3</td>
<td>14.0</td>
<td>99.9</td>
<td>3.5</td>
<td>1.9</td>
</tr>
<tr>
<td>2</td>
<td>72.0</td>
<td>8.5</td>
<td>19.3</td>
<td>99.8</td>
<td>8.4</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>66.6</td>
<td>27.2</td>
<td>6.0</td>
<td>99.8</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td>83.1</td>
<td>-</td>
<td>16.8</td>
<td>99.9</td>
<td>83.0</td>
<td>4.9</td>
</tr>
<tr>
<td>5</td>
<td>59.6</td>
<td>28.4</td>
<td>12.0</td>
<td>100.0</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>6</td>
<td>99.2</td>
<td>-</td>
<td>0.7</td>
<td>99.9</td>
<td>99.0</td>
<td>141.0</td>
</tr>
<tr>
<td>*7</td>
<td>76.5</td>
<td>5.3</td>
<td>18.2</td>
<td>100.0</td>
<td>14.4</td>
<td>3.2</td>
</tr>
<tr>
<td>8</td>
<td>87.6</td>
<td>11.2</td>
<td>0.1</td>
<td>99.9</td>
<td>7.8</td>
<td>7.7</td>
</tr>
<tr>
<td>*10</td>
<td>83.7</td>
<td>8.7</td>
<td>7.5</td>
<td>99.9</td>
<td>9.6</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Note: Numerals marked with asterisk refer to the columnar diagram shown in Fig. II
occurring among the Barakar rocks of the study area, comprising, to
the extent of 70 per cent of the total strata (Table 6). It weathers
commonly to buff colour but in places to brown or yellow. However,
on fresh surface it is generally earthy white to buff. It is friable
to indurated, but densely compact in places near fault planes or at the
contact of Deccan traps. Sandstone unit of this variety are by and
large thin- to very thick-bedded (McKee and Weir, 1953, p.383) ranging
in thickness from 0.5 to 2 m, lense shaped, and discontinuous, laterally
traceable from decameter to commonly a couple of tens of meter. By
and large the sandstone is elongate, straight to slightly curved in
cross-section and may occur both as 'multistorey' and multilateral
bodies. Bedding traces are faint to well developed and sharp to wavy.
Among the various internal structures of this sandstone, large-scale
cross-bedding is prominent. On the average it is coarse to medium,
slightly muddy, moderately to poor sorted feldspathic sandstone. This
sandstone grades into fine sandstone both vertically and, in places,
laterally. There is no much variation in the thickness of these
sandstones at different stratigraphic positions ranging from about 13
to 1P meters.

1.22 Fine Sandstone

This sandstone, weathering brown to yellow, generally forms the upper
part of coarse to medium sandstone. It is not persistent either
laterally or vertically, and is commonly overlain by siltstone.
The lower contact is invariably gradational but the upper contact is
often sharp and straight. Unlike the coarse to medium variety, fine sandstone is characterised by small scale cross-bedding and parallel lamination. Mineralogically, detrital particles consist mainly of quartz and feldspar. On the average this sandstone type shows a variable thickness from 4 to 9 m.

1.23 Siltstone
Siltstone in the Barakar formation is gray coloured and generally exhibits a sharp contact with the underlying units. Laterally siltstone is not extensive and may lens out at the outcrop within a short distance. It is generally harder than sandstone of the study area and is characterised by small scale cross-bedding and parallel laminations. Detrital grains comprise mainly quartz and carbonaceous material. On the average siltstone varies in thickness from 1.5 to 3 m.

1.24 Carbonaceous Shale and Coal
Outcrops of carbonaceous shale and coal are seldom well developed in the study area. These units are found to occur either just below the coarse to medium sandstone or above the gray siltstone (Fig. 11A and B). Bedding planes are straight to undulating and wavy. Laterally, these lithologic units are not extensive and tend to lens out within a few tens of meters. Thickness of carbonaceous shale and coal varies from a few centimeters to a few meters.

1.30 Motur Formation
The Motur formation is exposed as a continuous belt to the north of the Barakar formation along the entire length of the coalfield and
covers about 2/3rd of the area occupied by sedimentary rocks. Two mappable units have been recognised in the Motur formation, viz. Unit A (lower) and Unit B (upper). Since the bore-hole data through the Motur formation is not available, details of the lithologic association are based on three generalised stratigraphic sections measured along three different traverses in the area (Fig. 12). The lower Unit A of the Motur formation is characterised by abundance of red and green clay (or mudstone) whereas the upper Unit B is almost entirely made up of sandstone. The following lithologic types and rock association have been recognised for the lower and upper units of the Motur formation:

**Unit A**
(i) feldspathic pebbly conglomerate; (ii) fine pebbly coarse to medium sandstone; (iii) composite sequence and (iv) red and green clay/mudstone.

**Unit B**
(i) fine pebbly conglomerate (ii) coarse to medium and fine sandstone.

Approximate percentage (by volume) of broad lithologic types of the lower and upper units of the Motur formation is listed in Table 4.

1.31 **Feldspathic Pebby Conglomerate (Unit A)**
The feldspathic pebbly conglomerate forming the basal part of the lower Unit A outcrops at least at two localities in the study area; one to the north of the Head Office of the Poddar Co. just by the side of the Railway track (Plate 8A), and the other a quarter of a kilometer east of Harrai village (for locality, see Fig. 2, cover pocket). Even
Fig. 12 Measured stratigraphic sections of the Lower Unit A (A, B & C) and Upper Unit B (D) of the Motur Formation showing lithologic association and cyclic units; A. A Nazarpur - Richhara Section; B. Chandametta - Darwai Section; C. Maywari - Parasia - Section; D. Bichhua Section
though the lower contact is not available, the underlying Barakar rocks outcrop about less than 10 m away. This rock at these localities is somewhat wedge-shaped, lenses out laterally within about 30 m, and varies in thickness from zero to 3 m (Fig. 11). Lithologically, it is fine to medium pebbly conglomeratic feldspathic sandstone. The feldspar content is as high as about 60 per cent in this rock type. This mineral, mostly a fleshy coloured undecomposed feldspar (orthoclase) occurs as detrital grains in the sandy matrix along with quartz, forms most of the pebbles, and, by and large, is angular to subangular (Plate 2A ). Commonly feldspar pebbles are 3-0.5 cm in size, some are as large as 5 cm. Among other clasts are jasper, chert and some pebbles of granitoid and coarse sandstone (? Barakar). Unlike the feldspar pebbles, these clasts are subangular to subrounded. At both the localities, referred to above, these feldspathic pebbly units are overlain by red and green clay/mudstone.

1.32 **Fine Pebbly Sandstone**

Among the Motur sandstones, fine pebbly coarse to medium sandstone is conspicuous by virtue of its olive green colour and texture. This sandstone, however, occurs occasionally as interbeds varying in thickness from 9 to 15 m (Fig. 12), commonly as multilateral coalescing body. By and large it is straight to curved traceable for a few tens of meters. Its lower contact with the underlying unit is usually sharp and straight to wavy, whereas the upper contact is more or less gradational. Commonly these units are profusely cross-bedded. Pebble
EXPLANATION OF PLATE 8

A: Conglomeratic feldspathic sandstone forming the basal part of the Motur formation. The conglomerate abounds in angular feldspars.
Creek cutting, approximately 600 m north-northwest of Parasia.

B: Composite sequence showing rapid alternation of sandstone and red and green clay (mudstone).
Left bank of Pench river, approximately 1 km south of Darwai village.

C: Composite sequence of sandstone and shale.
Left bank of river Sukri, approximately 5 km north of Maywari.
components comprising about 10 per cent (by volume) of the sandstone, are compositionally heterogenous, representing mostly quartzose and granitoid rocks, and pink feldspars (orthoclase). They vary in size from less than 5 to about 10 mm, and by and large are subangular.

1.33 Composite Sequence

The term "composite sequence" has been applied here to those deposits of the Motur formation which include interbedded lithology of more than one kind. Van Straaten (1954, p.107) used the term "lateral deposit" for such lithologically heterogenous beds, whereas Allen and Friend (1968, p.43) applied the term "composite structure" to such deposits. These deposits are very common in the lower Unit A of the Motur formation. Some of the best exposures of these deposits are found south and southwest of Darwai in the Poonch river (Plate 9b), and southwest of Parasia in Sukri river (Plate 9c). At all these localities the composite sequence is floored by green to yellow fine pebbly sandstone having erosional contact with the underlying unit. The succeeding assemblage comprises inter-fingering lenses of coarse to medium sandstone and red and green clay. Broadly the composite sequence exhibits alternation of coarse and fine grade members with a general decrease in grain size from the lower to the upper part. In most places the composite sequence is, laterally, more or less continuous and varies irregularly in thickness from 5 to 9 m. Among the sedimentary structures, more common are large- and small-scale cross-bedding and parallel lamination which may occur successively in a vertical sequence.
1.34 Red and Green Clay/Mudstone

Among the lithologic types of the lower Unit A of the Motur formation, red and green clay/mudstone is widely occurring in the study area (Fig. 11), comprising as much as about 60 to 80 per cent (by volume) of the total strata (table 4). The colour of the Motur clays is indeed characteristic and helps in identifying and demarcating the limits of the lower Unit A of the Motur formation in the study area. However, red clay is by and large more abundant than green clay which generally occurs in small patches and lenses within the former. Since these clays are loose and friable and completely lack stratification, its approximate strike direction could only be determined when they occur interbedded with sandstone. Occurring at a few localities are small calcareous nodules of irregular shape which have been attributed to the "secretion products of lime" (Fox, 1934, p. 277; Pascoe, 1959, p. 956). Approximate thickness of these clays in the three stratigraphic sections is variable between 70 and 108 m respectively.

1.35 Fine Pebby Conglomeratic Sandstone (Unit B)

The upper Unit B of the upper Motur formation is dominated by fine to coarse pebbly conglomeratic sandstone comprising about 40 per cent of the strata (Table 4). The colour of this conglomeratic unit is variable from earthy yellow to gray, to red in places. It is generally weakly indurated except near the contact with Deccan traps where it becomes hard and massive. Conglomeratic sandstone is generally very thick-bedded ranging in thickness from 2 to about 3 m, and laterally extensive; locally, though, it may appear as pinching and swelling sheet. Among the
clasts of conglomerate, more common are those of quartzose composition of pink, gray and white variety; pebbles of granite and feldspar occur sporadically. Internal sedimentary structures include tabular and trough cross-beds. Vertically this unit grades into coarse medium sandstone within a few metres. Thickness of this unit may vary from 5 to about 10 m.

1.36 Coarse to Medium and Fine Sandstone

Coarse to medium and fine sandstone comprising about 50 per cent of the strata is by and large very similar to the sandstone of the Barakar formation. It is earthy yellow to buff in colour, and thin- to thick-bedded. Bedding traces within this lithologic type are straight to wavy, and occasionally marked by erosional channels. Laterally this sandstone is fairly extensive as a multilateral body, but vertically it gradually passes into fine sandstone. Tabular and trough cross-bedding of large-scale is fairly abundant. On the average it is a coarse to medium, moderately to poorly sorted, feldspathic sandstone. The total thickness of this unit commonly varies from 55 to 60 m.

2.0 SEDIMENTARY CYCLES

2.10 Talchir Formation

Early workers did not refer to the possibility of repetitive sequence in the Talchir formation. However, the present investigation in the study area reveals that the available Talchir rocks represent a composite assemblage which comprise three diamictite units - lower (A),
middle (B) and upper (C), each overlain by a group of fine clastics comprising sandstone and shale (Fig. 5). Thus the diamictite assemblage of the Talchir formation in the study area exhibits a repetitive (cyclic), broadly fining upward, sequence. The succeeding conglomeratic assemblage of the transitional zone (Unit D), likewise, represents a fining upward sequence comprising conglomerate at the base grading vertically upward into sandstone, interbedded sandstone and shale and shale. Among the lithologies which constitute the sedimentary cycles, the following, listed in descending order, are more well developed and common:

IV Shale
III Interbedded fine sandstone and shale
II Sandstone
I Diamictite

Diamictite of cyclic unit I may be replaced by conglomerate for transitional zone Unit D. The above sequence of cyclic units is rather generalised and it may be that a sedimentary cycle at each outcrop may not exhibit all the lithologic units listed above. Commonly the cyclic units in the Talchir formation of the study area are present in the following combinations: I, II, III; I, II; I, II, IV; I, II, III, IV. The diamictites are among the most widely occurring cyclic unit, and form about 52 per cent of the total strata (Table 4).

2.20 Barakar Formation

Fox (1931) and Krishnan (1956) reported the cyclic nature of the coal bearing Barakar sediments. Rao (1964) and Mehta (1964) recognised as many as 30 to 60 cycles in the Barakar formation of Jharia coalfield.

The lithologic sequence of Barakar coal bearing strata in Pench Valley coalfield exhibited in the bore-hole and stratigraphic sections (Fig. 11 A and B), by and large, corroborates the earlier view about the existence of a repetitive or cyclic sequence in this formation. Further, it was found in many outcrops that an upward decrease in the detrital grain size within each cyclic unit is accompanied by an appropriate decrease in the scale of available cross-bedding, a phenomenon reported earlier by Allen (1964, 1965a) and subsequently by others (Barrett, 1965; Friend, 1965; Duff et al., 1967; Allen and Friend, 1968; Casshyap, 1970). Apparently, the repetitive lithologic units of the Barakar formation in the study area qualify the characters outlined for a "fining-upwards" cycle (Allen, 1965a). However, in the present case the base of a cyclic unit is more often a wavy surface instead of a well developed "Scoured surface" (Allen, loc cit.).

A generalised "standard" cycle (Weller, 1956), proposed earlier for the Barakar formation of Peninsular India (Casshyap, 1970, p. 1309), is slightly modified for the study area (Table 7). However, as is to be expected, all the units of the "standard" cycle seldom occur at one place (Duff, et al., 1967, p.7), and in the Barakar formation of the
<table>
<thead>
<tr>
<th>Cyclic Units in descending order</th>
<th>Lithologic Character</th>
<th>Associated Primary Sedimentary Structures</th>
<th>Subdivisions of &quot;fining upward&quot; cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Coal, shaly coal</td>
<td>Parallel lamination and (or ) structureless</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Carbonaceous siltstone and shale</td>
<td>Parallel lamination and small scale-cross-bedding</td>
<td>Fine grade member</td>
</tr>
<tr>
<td>III</td>
<td>Interbedded sequence of fine sandstone, siltstone and shale</td>
<td>Parallel and wavy lamination, and small-scale cross-bedding</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Fine sandstone</td>
<td>Large- and small-scale cross-beding, and horizontal bedding</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Coarse to medium sandstone</td>
<td>Horizontal bedding and large-scale tabular and trough cross-bedding</td>
<td>Coarse grade member</td>
</tr>
</tbody>
</table>
Pench Valley coalfield the cyclic units are commonly "truncated" or "reduced" (Bersier, 1958; Duff et al., 1967), as is evident from the measured stratigraphic sections (Fig. 11A). These truncated or reduced sedimentary cycles comprise two, three, four or five lithologic units in the following combinations in ascending order, namely, I, II, III; I, II, IV; I, V; I, II, III; I, III, IV; I, II, III, V, and so on, and exhibit a wide range of variation in thickness, from 2 to 15 m on the average. Admittedly in the study area, with a few local exceptions, the lower coarse grade member comprising by and large 50 to 80 per cent (by volume) of a sedimentary cycle, is volumetrically more abundant and widespread than the upper finer grade member. Among the former, the lowermost unit (I) comprising coarse to medium sandstone is extensively developed. The overlying finer sandstone unit (II) and the succeeding units of the finer member are by and large local and seldom laterally extensive.

2.30 Motur Formation

Among the early workers, none so far, perhaps, has conceived cyclicity in the succeeding Motur formation of the Satpura basin or its equivalent 'Barren measures' of Damodar Valley coalfields.

The measured stratigraphic sections for the Motur formation of the study area, particularly for the lower Unit A, explicitly exhibit alternation of coarse- and fine-grade members (Fig. 12). The former is essentially fine pebbly, coarse medium sandstone and olive green to yellow in colour and the latter dominantly red and green clay. Particle size and
cross-bedding and other sedimentary structures in the lower coarse member show an appropriate and systematic decrease in the upward direction within each unit. The upper fine grade member is more or less structureless but may exhibit locally faint parallel lamination. The above features recall those of fining upward sequence, referred to earlier. Inasmuch as these rocks are devoid of coal and seldom contain carbonaceous shale, a modified sequence of "standard" cycle is proposed for the lower unit A of the Motur formation as follows in descending order:

Fine grade member (IV) Clay or mudstone occasionally interbedded with sandstone (III) Fine sandstone and siltstone

Coarse grade member (II) Coarse to medium sandstone (I) Pebbly conglomeratic sandstone

As for the Barakar strata, the cyclic sequences in these rocks are more often 'truncated' or incompletely developed (Fig. 12) and the following combinations of cyclic units are particularly noteworthy. I, II, IV; I, II, III, IV; I, IV; and so on. Many of these sedimentary cycles vary irregularly in thickness from 10 to 35 m. Evidently, coarse grade member is relatively poorly developed in the cyclic sequence of the Motur formation, ranges in thickness from 3 to 18 m and on the average constitutes about 24 per cent.

In contrast fine grade member, ranging in thickness from 81 to 105 m, forms the bulk of a cyclic sequence (73 per cent) in the Motur formation and in most cases fine exceeds the coarse member. Indeed, fining upward
cycles of the lower Unit A of the Motur formation are strikingly different from those of the coal-bearing Barakar formation in which, as a rule, coarse grade member exceeds fine. The available upper Unit B of the Motur formation in the study area predominantly comprises sandstone. Nevertheless fining upward cycles are not uncommon (Fig. 12). These are represented dominantly by coarse grade member comprising two to three cyclic units in ascending order: (I) Pebbly conglomeratic sandstone, massive to cross bedded, (II) coarse to medium sandstone, commonly cross-bedded and (III) fine sandstone. The succeeding finer grade member of red and green clay is poorly and locally developed.

3.0 PRIMARY SEDIMENTARY STRUCTURES

The study of sedimentary structures was undertaken with a three fold object (1) to examine and describe at length the morphology of each available "primary sedimentary structure" (Pettijohn and Potter, 1964, p. 3), (2) to infer the probable flow conditions of depositional currents, and (3) to measure and analyse appropriate directional parameters for the purpose of reconstruction of palaeocurrent patterns. The last aspect has been dealt with at length and forms the subject matter of the following chapter.

Inferences about the hydraulic conditions of depositional currents are based on the premise that an empirical relation exists between water flow and the development of the various forms of bed roughness (Dawdy, 1961; Simons and Richardson, 1961, 1962). Two flow regimes, lower and upper, recognised in alluvial channels produce an appropriate sequence of
bed forms with increasing intensity of flow, and include parallel lamination and ripples, through dunes, to plane bed and antidunes (Simons and Richardson, 1961, 1962). In view of the known genetic significance of the subaqueous bed forms, the sequence of primary sedimentary structures expected to be developed as a result of increasing intensity of flow has been appropriately outlined by several subsequent workers (Allen, 1963b; Simons et al., 1965; Harms and Fahnestock, 1965).

Listed below are primary sedimentary structures recognised in the Talchir, Barakar and Motur formations of the study area: (1) horizontal bedding; (2) cross-bedding; (3) parallel lamination including rhythmites (varvites), and (4) channels and scour and fill.

3.10 Horizontal Bedding
This feature is very common in sandstones of the Talchir and Barakar formation (Plate 9A). In the Talchir sandstone, horizontal bedding generally occurs in continuous units traceable for tens of meters. In sandstones of the Barakar formation it occurs locally as discontinuous lenticular units. Thickness of horizontally bedded unit rarely exceeds a meter. The individual bedding is marked by change in grain size, composition of mineral cement or contained matrix, or by the change in composition of detrital mineral assemblage. Horizontally bedded sandstone is commonly associated with cross-bedded sandstone, but may occur with massive sandstone and less commonly with siltstone or coal.

Horizontal bedding in sandstones is more probably a product of plane bed
EXPLANATION OF PLATE 9

A: Horizontal (flat bedded Talchir sandstone
Creek cutting, approximately 4 km southwest of Khairwani village.

B: "Coset" of moderate large-scale tabular cross-bedded units in medium to coarse Barakar sandstone with planar to erosional lower contact.
Creek cutting 3 km south-southwest of Jatachapur village.

C: A "solitary" Unit (set) of large-scale tabular cross-bedding in medium to coarse Barakar sandstone.
A creek cutting north of Railway track approximately 3 km northwest of Parasia.
formed from strong currents in a upper flow regime (Harms and Fahnestock, 1965, p. 105). Local and occasional occurrence of horizontally bedded sandstone unit may imply either a periodic (seasonal) increase in flow velocity due to increase in discharge, or a decrease in depth of water due to upbuilding of bed forms or aggradation (vertical accretion) of sediments.

3.20 Cross-Bedding

The term cross-bedding (see Potter and Pettijohn, 1963, p. 68), also called cross-stratification (McKee and Weir, 1953, p. 383), refers to a large group of related sedimentary structures of varied nomenclature and classification (Lahee, 1952; McKee and Weir, 1953; Botvinkina, 1959; Potter and Pettijohn, 1963; Allen, 1963b; Elliot, 1964). The schemes of nomenclature and descriptive classification advanced by Potter and Pettijohn (1963) and Allen (1963b) are indeed more meaningful and practical, and are those used in the present investigation. Geometrically, cross-bedding may be tabular (planar) and trough shaped, and may occur either as a single or solitary unit (set) or vertically in successive units (cosets or grouped sets). On the basis of scale (or thickness) of cross-bedded set, a distinction may be made between large-scale cross-bedding, in which average thickness of a set in a coset is greater than 4 cm, and small-scale cross-bedding in which thickness of a set is less than 4 cm (Allen, 1963a, p. 188, 1968, p. 100).

3.21 Large-scale Cross-Bedding

In the study area large-scale cross-bedding is profusely developed in the
Barakar and Motur formations and sporadically in the Talchir formation. It is represented by both tabular and trough shaped.

Large-scale tabular cross-bedding is, however, predominant and well displayed three dimensionally in the Barakar and Motur formations and is less common and locally well displayed in the Talchir formation. It is largely developed in medium to coarse and fine sandstone, and locally in conglomerate. Individual foresets of tabular cross-bedded unit may be strictly planar although or are tangential to the base and truncated at the top. Their length may vary from a few decimeters to about 2 meters and thickness from about 2 to 10 cm. Tabular cross-bedded units occur generally in grouped sets or cosets (Plate 9B) and occasionally in solitary sets (Plate 9C). Cross-bedded cosets which may be less than a meter to a maximum of 4 m thick are traceable in outcrop from a couple of meters to more than a decameter. Solitary sets are commonly half a meter thick or less and seldom exceed laterally a few meters. A total of 497 measurements for thickness of cross-bedded units were recorded from Talchir (20), Barakar (263) and Motur (214) formation (Appendix II), and grouped into 10 cm (4 inch) class-interval, the data were plotted as per cent frequency histograms (Fig. 13). By and large thickness of cross-bedded units varies from less than 10 cm to about 1 m in the Talchir, Barakar and Motur formations. The average thickness of cross-bedded unit is 37.5 cm; 33.0 cm and 26.7 cm, respectively, for Talchir, Barakar and Motur sandstones. Although inclination of cross-bedded foreset beds in all the three formations ranges from 5° to 40°, values between 20° and 25° are more common. Average
Fig. 13 Frequency distribution of thickness or scale of cross-bedded units of the three formations of the Pench valley coalfield.
inclination of foresets is 26°, 23° and 23°, respectively, for Talchir, Barakar and Motur sandstones (Fig. 14).

By and large the characters of tabular cross-bedded cosets and solitary sets are similar to those of 'Omkron-cross-stratification and 'Gamma-cross-stratification of Allen (1963b, p. 102-103).

Large-scale trough cross-bedding is not so widespread as the tabular cross-bedding in the three formations and is relatively more common in the Barakar formation. Trough cross-bedded units in cosets are more often available in vertical a-b section (Plate 10 A) and horizontal a-c section, and less so in vertical b-c (strike) section. Each set is underlain by a scoop-shaped erosional surface and are formed of more or less symmetrical cross-strata. The trough cross-beds of the study area closely resemble Allen's (1963b, p.110) 'Pi-cross-stratification'.

It is now generally accepted that large-scale cross-bedded units are formed from stronger turbulent current in a lower flow regime that had generated delta- or dune-like bodies of sediment engaged with eddies to the lee sides as the result of flow separation (Allen, 1963a, 1968, p. 97; Jopling, 1964; Simons et al., 1965, p. 38). Extending the analysis further, the solitary cross-bedded sets, tabular in form, may suggest isolated migratory bars, perhaps emergent, like those of braided streams (Leopold and Wolman, 1957; Krigstrom, 1962; Allen, 1963c), or submerged at shallow depths as seen in the Rio Grande (Harms and Fahnestock, 1965, p. 103). Tabular cross-bedded units in cosets are
Fig. 14 Histograms showing inclinations of foreset beds in the cross-bedded units of Talchir, Barakar and Mutur Formation.
more probably built by down current migration of large straight symmetrical ripple trains (Hulsemann, 1955; Allen, 1963a) or transverse bars (Simons et al., 1965; p.42; Harms and Fahnestock, 1965). As demonstrated by Allen (1968, p.119), it seems large-scale trough cross-bedded cosets can be generated by the migration of any kind of large ripples whose trough is closed or which contains closed hollows, as for example "quasi three dimensional straight ripples", "transverse catenary ripples" and "lunate ripples". However, several workers have advanced alternative mechanism to explain the origin of water-laid cross-bedded cosets of trough shape (Kneight, 1929; Stokes, 1953; Mckee, 1957; Harms and Fahnestock, 1965). A schematic diagram (Fig.15) based on calculated average thickness of cross-bedded units, and inclination and length of foresets, shows the average dimensions of the migrating large-scale ripples which may have produced the cross-bedding cosets of Talchir, Barakar and Motur sandstones. Probable average depth of water inferred from the average thickness of cross-bedded units (Allen, 1963a, p.198) is indicated in the figure.

3.22 Small-Scale Cross-Bedding

Small-scale cross-beds are restricted to fine sandstones and siltstones of the three formations and make up a small proportion as compared to large-scale cross-bedding (Plate 10 649). Unlike large scale cross-beds this structure often occurs in thin (about decimeter) cosets. The thickness of individual sets may vary from less than a centimeter to a few centimeters. Small-scale cross-beds of the study area in b-c sections
Fig. 15 A schematic diagram showing average dimension of the migrating sandwaves during the deposition of Lower Gondwana rocks
bear close resemblance with those of Allen's (1963c, p.107) 'nu-cross-stratification'. However, along the bedding plane surfaces in the a-b section this structure is very similar to "micro-cross lamination" of Hamblin (1961) and 'rib and furrow' structures of Stokes (1953). The lower bounding surfaces of small-scale cross-beddings are generally non-erosional inasmuch as the foresets of one set extend downward into the subjacent set.

Following Sorby's meticulous insight (1859, 1908), it is now widely believed that small scale cross-bedding results from the downward migration of small-scale ripples under sediment supply condition that permit the successive generation of rippled surfaces (Allen, 1963a; McKee, 1965). Thus, the nu-cross-bedding probably record migration of small-scale linguoid ripples (Allen, 1963b, pp.106-107). This structure is known to develop from weaker currents in a lower flow regime (Allen, 1963c, fig. 3, 1968).

3.30 Parallel Lamination

This structure is predominant in green needle shale of Talchir formation as well as locally developed in carbonaceous and muddy siltstones of the Barakar and Motur formations. In the Talchir shale parallel laminations, are generally about 0.5 cm thick and are, not uncommonly laterally traceable in some cases for about a few tens of meters. These laminations are straight to wavy and faint to well developed. However, at least at one locality the shale unit interbedded with diamictite Unit C conspicuously exhibits laminations which are alternately thick
EXPLANATION OF PLATE 10

A: A set of trough cross-bedded unit overlain by large-scale tabular cross-bedded coset in medium to coarse Barakar sandstone.
A creek cutting, approximately 1 km south-southeast of Bhaljipani.

B: Superposed assemblage of small-scale cross-bedding in fine carbonaceous sandstone of the Barakar formation.
Creek cutting, approximately 1 km southwest of Parasia.

C: A specimen of fine sandstone and siltstone of the Talchir formation showing on polished vertical face foresets of small-scale cross-bedding.
Creek cutting, approximately 4 km southwest of Khairwani village.
(1 to 2 cm) and thin (less than 1 cm) showing a well marked gradation of particle size from fine sandstone to coarse silty at the base to fine silt and clay near the top (Plate II A). This sequence of laminations closely resembles "varves" (Pettijohn, 1957a, p.353). Parallel laminations in the Barakar (Plate II B) and Motur siltstones may be regularly horizontally spaced or irregularly arranged. The former may be attributed to slow settling from suspension in quiet water (Horns and Fahnstock, 1965, p.109) whereas the latter to slightly turbulent water without adequate supply of sediments.

3.40 Ripple Marks

Schrock (1946, p.93) defines ripple marks as "undulating surface sculptures produced in non-coherant granular materials by the wind, by currents of water, and by the agitation of water in wave action". The study of ripple marks is useful in determining the palaeocurrent direction, environment of deposition as well as the hydrodynamic conditions under which they were developed.

Ripple marks occur sporadically in the study area and are particularly common in medium to fine sandstone of the Talchir formation. They are asymmetrical in form (Plate II C) except in a few outcrops where they appear to be symmetrical. Their crests are more or less rounded and laterally gently undulating to bifurcating; amplitude varies from 1.0 cm to about 3 cm in some Talchir sandstone (Plate II C) and wave length from 16 cm to 25 cm. Most of these ripple marks are similar to Allen's (1968, p.65) 'Transverse sinuous' ripple trains. Ripple index,
EXPLANATION OF PLATE 11

A : Embedded in a massive diamictite is a lenticular body of laminated shale consisting alternatingly of coarse siltstone and clay. The structure resembles varves.

Creek cutting, approximately 4 km south-southwest of Sukri village.

B : A polished specimen showing parallel and wavy laminations in the carbonaceous siltstone of the Barakar formation.

Pench River cutting, approximately 1 km southwest of Setia village.

C : Slightly asymmetrical ripple marks in the Talchir sandstone.

Creek cutting, approximately 3 km south-southwest of Khairwani village.
namely, ratio of wave length to amplitude (Potter and Pettijohn, 1963, p. 93) computed for the three formations ranges from 17.3 to 20.0, but in a few cases it is below 10. Admittedly all the values occur well within the range of 4 to 20 which is characteristic of aqueous ripples (Kindle and Bucher, 1932; Twenhofel, 1950). Ripple indeed for eolian ripples is known to be higher than aqueous ripples (Kindle and Bucher, 1932; Schrock, 1948).

It is now an accepted view that current ripples represent a fundamental form of bed roughness and are generated in lower flow regime where the resistance to flow is large.

3.50 Channels and Scour-and-Fill

Small to large erosional channels from about a meter to more than 10 meters wide and from a few centimeters to about 3 meters deep commonly occur in Unit D of the Talchir formation and medium to coarse sandstones of the Barakar and Motur formations and represents an erosional surface. In the Barakar and Motur formation (Plate /2 ) these channel sandstones are apparently massive, however, in some places the channels are not wide and deep and are filled in with cross-bedded strata and resembles 'scour-and-fill' structure (Schrock, 1948, p. 230) or 'ripple scours' (Potter and Glass, 1958).
EXPLANATION OF PLATE 12

Channeled sandstone in the Motur formation showing in the foreground. In the background are smaller features resembling scarp-and-fill structures.

Left bank of Pench river, approximately 4 km east-southeast of Dorli village.