Chapter Six

SEDIMENTATION AND ENVIRONMENT

The area under study is covered mostly by sedimentary rocks which have either escaped or undergone very feeble metamorphism and are by and large restricted at the most to chlorite schists (green schist facies). The Udaipur valley represents unmetamorphosed rocks which show progressive metamorphism towards the north as well as the south and it has been observed that the metamorphic isograds run approximately east-west, across the regional strike of the formations. This, however, requires detail study and it is
beyond the scope of the present work. Most of the rocks in the present area display excellent sedimentary structures and they are described and discussed from the point of the environment of sedimentation.

For the sake of simplicity the formations are divided into four lithological units and have been dealt separately. Namely, group I, the rudaceous rocks (conglomerates and grits), group II, the arenaceous rocks (quartzites and arkoses), group III, the argillaceous rocks (shales and laminites) and group IV, the carbonate rocks (limestone and dolomitic limestone). This purely lithological classification may sometimes cut across the stratigraphic succession.

**Group I - Rudaceous rocks:**

This group is represented by the conglomerates and grits of the basal Aravallis (Delhis according to Heron). The field relations and lithology of these rocks have already been discussed in an earlier chapter.

In general, the conglomerates are orthoquartzite (oligomict) conglomerates (Pettijohn, 1957, p. 255-256). The pebbles are mostly of quartzites of variable colours and lithology, the dark grey quartzite pebbles being the most abundant. Next come the grey, white and pink quartzites and vein quartz pebbles. Phyllites are also represented as
pebbles although in a very insignificant quantity. The pebbles are mostly of irregular triaxial ellipsoidal shape (Pl. 4, Fig. A) and are very well-rounded to angular. The matrix is arkosic to quartzitic. The framework is much affected by deformation and wherever it is unaffected it is of close framework.

The size of the pebbles and their shape are much variable. The strongly deformed character of the pebbles can be seen from the ratio of their principal axes (30:7:3). The pebbles also show a preferred orientation. In general, they appear to be related to tectonic axes. In some instances their orientation is influenced by the fore-set bedding of the torrential cross-bedding. The extent of preferred orientation developed by the current and by the tectonic forces is rather difficult to estimate. It appears that the current definitely contributed to the final picture, by bringing about an initial preferred orientation in the pebbles at the time of their deposition. The problem of initial orientation always becomes complicated in an area which has undergone repeated deformation. It is thought that much of the elongation seen in the pebbles must largely be due to stretching along 'a' or 'b' tectonic directions. Nevertheless there is a distinct possibility that a large number of pebbles were initially prismatic and that they had a preferred orientation.
prismatic and that they had a preferred orientation. Studies on similar types have shown that rolling produces a preferred orientation where the longest axis is at right angles to the current direction. Whereas, if the pebbles become buoyant under the higher concentration of the particles in the flow, then it shows up current imbrication towards the fore-set bedding of the torrential cross-bedding (Pettijohn, 1957, p. 250; Potter and Pettijohn, 1963, p. 35–36). The critical quantity of particle concentration to the current strength largely governs the above two types of pebble orientation but is influenced by a number of other variables which would require a very detailed study to arrive at a definite conclusion. The pebbles are sometimes arranged in the fore-set beds of cross-bedded strata (Pl. 4, Fig. D) and they show positive grading.

The contact of the conglomerates with the grits and arkoses is gradational. In the gritty part the bedding plane contacts are clear and cross-bedding is common (Pl. 5, Fig. A). The cross-bedding is mostly of the torrential type. The angle between the normal bedding plane and the fore-set beds varies from 20° to 40°. The thickness of the cross-bedded strata varies from 10 cm to 4–5 meters. Large stray angular pebbles are often seen in these rocks.

As the strata represent an overturned sequence and suffered repeated deformation, it is difficult to deduce the current
direction on the basis of cross-bedding. At a few favourable spots the current direction was estimated by unrolling the present position of the strata to its pre-deformation position. In such cases the current direction is found to be westerly. Fanning of the current to north and south was also observed.

In view of the lithology, sedimentary structures and distribution of these rocks, the sediments appear to represent shallow water proximal deposits.

**Group II - Arenaceous rocks:**

The arenaceous rocks are represented by four varieties:

Sub-group 1 - Thick cross-bedded quartzite and arkose strata

Sub-group 2 - Quartzite bands with pelitic layers of turbidite-like appearance

Sub-group 3 - Thin quartzite bands within the Aravallis

Sub-group 4 - Laminated quartzite of variable thickness

Sub-group 1 - Thick cross-bedded quartzite and arkose strata.

This sub-group is represented by the quartzites and arkoses assigned Delhi age by Heron. The bedding plane contacts are sharp in the thick cross-bedded strata. Cross-bedding is of simple type (Weller, 1959, p. 104) and this indicates the top and bottom of the succession. The
determination of current direction on the basis of cross-bedding is difficult on account of deformation but wherever it could be determined it was found to be westerly. The horizon with torrential cross-bedding is succeeded by a horizon with distinct symmetrical (oscillation) ripples (Pl. 7, Fig. D). Here the bedding planes are distinct and the cross-bedding is absent. In this horizon quartz is more or less the only mineral present and felspar, insignificant. The arkosic character of the lower horizon being completely lost.

On the basis of the lithology (discussed in an earlier chapter) and the nature of sedimentary structures, these quartzites and arkoses appear to be genetically connected with the conglomerates and grits (discussed earlier) and together form the shallow water zone of the paleo-geosyncline in this region.

**Sub-group 2** - Quartzite bands with pelitic layers of turbidite-like appearance.

The cross-bedded quartzites and arkoses around and south-east of Eklingji have bands of laminated and non-laminated arenaceous rocks with variable thickness and proportion of pelitic sediments. The importance of this horizon is in the presence of very distinct under surface markings and other sedimentary structures very typical of turbidity deposits.
Figure D, plate 5 and figure A, plate 6 show two cases of under surface markings. Figure D, plate 5 represents longitudinal inverted spoon structures, the direction of flow being at right angles to the depositional strike of the region. Figure A, plate 6 represents another variety of the flute casts on a bigger scale. The width is more in this case than in figure D, plate 5 but the linear arrangement is distinct and is again at right angles to the depositional strike.

These two cases illustrate high density viscous flows and represent earlier stages of the turbidity current movement. As such lithologically the quartzite bands represent cleaner sands in relation to the other types to be described in succeeding paragraphs.

Sedimentary structures associated with quartzites (laminated) having considerable quantity of pelitic component are represented in plates 21 (Figs. B and C), 22, 23 and 24. Figure C of plate 21 represents a polished surface of a block cut across the bedding plane and oblique to the cleavage. The dark coloured portion is much pelitic (muddy sand) and the light coloured portion is sandy. In the lower half of this figure the sandy portion shows distinct lensoid and irregular bedding. It is traversed by a normal fault of the soft sediment stage. Though the displacement is small it is very clear between the middle sandy layer and the base of
the upper sandy layer. There are a number of small sedimentary injections which have taken place along the cleavage planes. They can be traced and connected with their mother layer.

In this case the emplacement of these auto-injections along the cleavage planes has considerable significance. It is indicated that due to some cause, may be, like the load of overburden of small thickness, pressure was increased beyond the critical stage (causing expulsion of water) on this strata. It has been recorded by Maxwell (1962) and Williams et al. (1969) that under these conditions the sandy portion becomes more or less fluid and may give rise to rotation of minerals leading to a cleavage like the axial plane cleavage or the flow cleavage. This is synchronous with the early stage of tectonic movement or a penecontemporaneous deformation or both. The compaction of the sediments lead to compression of these small injections as shown in figure B and figure C of plate 21. Such structures are common in this horizon and support the view of Williams et al. that there is a complete gradation between tectonic and penecontemporaneous deformation structures. Furthermore there is probably a complete range of conditions of deformation from fluid sediments through deformation of unconsolidated sediments induced by tectonic folding to deformation of lithified rocks under high temperature and pressure conditions. It seems, therefore, that the flow cleavage can at times be of prediagenetic stage.
Plate 22 represents a polished surface of a specimen from
the same horizon and with the same lithology as described for
figures B and C of plate 21. The sedimentary structures
represented are in a way a combination of those represented
in figures B and C of plate 21 except for the lowermost zone
and certain muddy (pelitic) injections of pre-diagenetic
stage. The lowermost zone (No. 1) is a zone of convolute
laminations. A sand dyke marked (S) is present. The contact
between zone 1 and zone 2 is very sharp and the top of zone 1
is eroded one. Zone 2 is a non-laminated pelitic zone in
which there is a sedimentary injection (marked M) of the
composition of muddy sand. In alignment this injection is
parallel to the sandy injection S. Zone 3 is a zone of sandy,
lenoid and irregular bedding in the pelitic matrix. The
irregular bed marked G in this zone is graded. Grading is
positive and it confirms the top and bottom fixed by the
erosion of convolute laminations (zone 1). Zone 4 is composed
of sandy beds with penecontemporaneous deformation and lenoid
bedding. Zone 5 is an irregular pelitic layer. Zone 6 is a
sandy bed, thick on the left and thinning towards the right.
The upper and the lower contacts of this bed are sharp but
the bed is pensymmetrically graded (positive grading at the
lower contact and negative grading at the upper contact).
Zone 7 is a zone of parallel pelitic and psammitic laminations
with a few shreds of sandy layers in which there is positive
grading. A muddy injection marked L is running through this
zone which seems to be connected with the pelitic matrix of zone 5. Zone 8 is like zone 6 but shows cross-laminations on the left. No grading is seen in this zone. Zone 9 is very much similar to zone 7 but the lower part is more sandy and there are small sandy lenses. Zone 10 represents structures very much similar to those represented in figures B and C of plate 21. Sedimentary injections of sandy fraction are present which are again deformed. In the lower portion of this zone there seems to be other injections of mixed lithology and in a different alignment. Zone 11 is a pelitic interval between the lower deformed and disturbed zone 10 and the upper sandy parallel laminated zone 12. Zone 12 is a zone of laminated quartzite. The lower portion of this zone is irregularly injected into the upper laminae (injection marked L1).

Plate 23 represents a polished surface of a specimen from the same horizon and of the same lithology as described in the previous paragraph. The average grain size is around 0.1 mm in pelitic fraction and around 0.5 mm in the sandy fraction. The polished surface in this figure is cut across the bedding surface and is oblique to the prominent cleavage plane. This starts with a dark pelitic zone (1) having a sandy band lensoid bedding just at its base of it. The arrow in the figure shows an irregular sedimentary injection of sandy mud fraction in the dark pelitic zone. This phenomenon has already been explained and it is due to penecontemporaneous syntectonic deformation. Zone 2 represents parallel laminations
with incipient cross-ripple laminations in the upper portion and a distinctly load casted base. There is a fault in the left hand portion of this zone which is clear and continuous in the lower as well as the upper zones. This fault is definitely of a soft sediment stage and is a reverse fault. Zone 3 is lithologically in continuation with zone 2 but has distinct cross-ripple laminations which has been severely eroded on the top portion. Zone 4 is a zone of pelitic nature similar to zone 1 but shows sand pockets and disturbed bedding. Zone 5 is a zone of light coloured sandy constituents. This zone shows strikingly prominent lensoid bedding with high convexity of the lower side and low convexity on the upper side. Zone 6 is a zone of alternate layers of pelitic and sandy composition. In this zone the light coloured material shows segregation into balls and pocket structures. Zone 7 is a thick dark coloured pelritic zone which is capped by a very thin light band with lensoid bedding.

The alternate laminations indicate low viscosity conditions and deposition under cohesionless condition. As such these laminations represent the tailing effect of the pulsating turbidity flows.

Figures A, B, C and D of plate 24 represent X-ray radiographs of the samples from the same horizon described in the previous paragraphs (Pl. 21, Figs. B and C; Pls. 22 and 23). The X-ray radiographs were taken on a medical X-ray
unit. The rock samples were prepared for radiographic treatment following the technique of Hamblin (1962) and the modifications suggested by Patchen (1967). The thickness of the samples was kept at 3 mm. The samples were exposed on a non-screen film with the X-ray unit set on 40 K.V. and 60 miliampere-second (MAS). The distance between the X-ray and the object was kept 40 cm.

In figure A, plate 24, zone 1 is a pelitic horizon with a distinct sedimentary injection (marked I in the lower left hand side) which has been compressed vertically and the trend of the injection is parallel to the prominent cleavage trace. There is an irregular and ill-defined sandy layer at the base of this pelitic zone 1. Zone 2 is a quartzose band with pelitic layers dispersed throughout the zone. An interesting feature is that the lower junction of zone 2 (with zone 1) shows prominent load casting. The top of zone 1 shows distinct flame structures which are highly indicative of the stratigraphic top in this case as both the positive and negative grading are present in the upper zones of this sample. Zone 2 is topped by a coarse graded horizon which shows negative grading. It will be worth noting here that zone 4 represents a much coarser fraction without grading and zone 3 is a thin layer of clay laminae within zone 4. This suggests that the coarse graded fraction of zone 2 is more or less continuous up to zone 4. Zone 5 is again pelitic (like zone 1) but little coarser in grain size, with very delicate load casts and a
Light lensoid bedding at the base. The load casting and the lensoid bedding at the base have become clear only in the X-ray radiograph. The upper portion of zone 5 is succeeded by a coarse sandy horizon (zone 6) like zone 4 but here it shows a distinct positive grading which is repeated in zone 7. This rhythemic grading is indicative of the pulsating nature of the flow responsible for the deposition.

Figures B, C and D, plate 24 represent X-ray radiographs of one succession only. Different sections were taken from a single sample to study the deformation of the load casts (marked L) in zone 3 and the nature of lensoid bedding in zone 4.

Zone 1 is a fine-grained pelitic horizon more or less non-laminated. Zone 2 is a quartzose, light coloured and coarse-grained band of which the lower part is not graded but the upper part shows distinct positive grading. The transition between zone 2 and zone 3 is very gradual and no sharp contact exists. In zone 3 there is a load cast (Fig. B) which has been laterally compressed and deformed (Fig. B to C to D). There is a distinct lithological break between zone 3 and zone 4. Zone 4 starts with lensoid bedding (of plano-convex shape) with the convexity upwards indicating the deposition of the bed under a diminishing current velocity. In figure D the lensoid bed is also deformed along with the load cast in zone 3. There are delicate flame structures at
the base of the lensoid bed in figures B, and C, plate 24.

This is rather interesting that the contact between zone 1 and zone 2 is very sharp but the contact between zone 2 and zone 3 is completely gradational. Furthermore the coarse-grained zone 2 is itself laminated, though on a sub-microscopic scale but still very distinct. The presence of load cast, as disclosed by the X-ray radiograph, shows that the coarse material can penetrate to a considerable depth in pelitic portion.

The presence of cleavages has also been disclosed by the X-ray radiograph but they are not very persistent. The X-ray radiographs have distinctly shown that the pelitic material which appears homogeneous under the microscope is not so but is a mixture and has distinct structures like load casts and flame structures. This is recorded to indicate that even in these conditions the sediments were not really cohesionless as the laminations appear to indicate.

**Sub-group 3 -** Thin quartzite bands within the Aravalli rocks.

They are: (i) the quartzite band, west of Iswal, (ii) quartzite-grit band, around and south of Iswal, and (iii) the ridge quartzites, exposed in the north-east of the area.

The ridge quartzite has a very limited occurrence in this
area. These quartzites are fine-grained and the bedding plane contacts are distinct, current direction being westerly when cross-bedding is observed.

In the quartzite band west of Iswal, bedding plane contacts are not always distinct. Grain size varies from fine sand to coarse sand. The grains are angular to sub-angular. In hand specimen the quartzites sometimes appear massive.

The quartzite-grit band around Iswal and extending southwards is in direct contact with the dolomitic limestone (Raialo of Heron) and probably represents an interfingering succession of the quartzite-limestone-phyllite (laminated carbonaceous shales) sequence. The eastern margin of this quartzite-grit outcrop is lithologically a fine-grained variegated orthoquartzite with practically no felspar. The grain size and felspar contents progressively increases to the west. On the western margin the rock is mostly gritty and lithologically merges into sub-arkose (less than 10% of felspar). The grain size is of fine sand (in orthoquartzites) and coarse sand (in grits). The grains are mostly angular. The sedimentary structures are not well-preserved due to intense shearing in this zone but at places torrential cross-bedding is observed. Bedding planes are sometimes seen in the orthoquartzite otherwise they are usually indistinct.

In view of the lithology and sedimentary features of this association of orthoquartzite-grit and dolomitic limestone,
this thin belt seems to represent the orthoquartzite-carbonate consanguineous association (Pettijohn, 1957, p. 610-615). The environmental conditions for this association are, therefore, neritic to intertidal.

Sub-group 4 - Laminated quartzites of variable thickness.

This sub-group is represented by the quartzite bands in the Aravalli phyllites. These quartzites are mostly lensoid bodies of variable thickness and lithology, although the gross lithology remains the same. The dark inky purple quartzites around Rama and thin calcareous and carbonaceous quartzite bands in Katriawan valley and west of Iswal are included in this sub-group.

Figures A and B, Plate 11.

These two figures represent two polished surfaces of the same specimen. The specimen represents a laminated calcareous quartzite-shale sequence. It has a high porosity and shows considerable leaching. These two polished surfaces are roughly at right angles to each other and both are across the bedding.

Lithologically the light coloured bands are composed of quartz and some dolomite. Dolomite is of replacement character. The absence of felspar is pronounced. The grain size varies from 0.01 mm to 0.05 mm. The dark coloured laminae are composed mostly of clay material and a subordinate quantity of
carbonaceous matter, both of which are sub-microscopic. Few quartz grains are seen distributed in this fine-grained mass.

**Figure A:** The figure starts with a bottom zone of parallel laminations (zone 1) defined by uniform laminations parallel to each other and composed of dark clayey material. This zone is succeeded by a turbid mass with dark laminae showing soft sediment deformation. The discontinuity indicates that this was a turbid mass (zone 2a) and was not allowed to settle into continuous laminae. Sub-zone 2a is succeeded by sub-zone 2b having more clayey laminae but still is in a disturbed state. In this zone there are ripple laminations and small scale sand pockets. The upper surface of this zone has undergone slight erosion before the next zone was deposited. The laminations have been further complicated by the introduction of some concretionary structures of various shapes and colours (marked X). Zone 3 is a zone of parallel undulating laminations consisting of alternate dark and light coloured laminations. In a total thickness of 13 mm, 11 laminations could be counted. The dark laminations on the top of this zone show strong erosion before zone 4 was deposited. Zone 4 is again a mixture of light coloured quartzose layers with irregular and disrupted streaks of dark coloured clay laminae. The dark streaks in the middle of this zone indicate stoss side of cross-ripple laminations, the lee side of which appears to be a little thick. Though the grading is absent, the heterogeneous assemblage and clouded appearance with soft
sediment erosion of the laminae is strongly suggestive of its
turbid but highly fluid state at the time of emplacement.
While deciding the top and bottom much reliance has been placed
on the erosional surfaces as indicating upper surface of the
strata. It may be mentioned that in samples having well-
developed cross-ripple laminations with erosion surfaces, the
erosion surface tallies with the upper side of the strata as
indicated by the cross-ripple laminations. These cross-ripple
laminations appear to be identical to those described by
Walker (1963) as 'ripple drift of type three'. The morpholo-
gical character of these cross-ripple laminations is a special
feature of turbidity current deposits (Walker, 1963). Zone 5
again represents parallel and thin laminae with dark and
light colours. The measurements show 18 laminae in a thickness
of 10 mm of the zone. The laminae show slight undulations but
strict parallelism. The alternation of parallel laminations
with sandy turbid mass shows that each turbid flow probably
tailed off by almost non-viscous currents which deposited the
undisturbed clay laminae. The quartzose laminae were well-
differentiated. This separation indicates settling under free
non-viscous conditions and probably very much slower than is
ever possible in a turbidity cloud. All this has been mentioned
to indicate that this horizon does not lie within the massive
turbidity flow zone where such quick alternations would not be
possible. This succession fits in Tₐ-b succession described
by Bouma (1962) and indicates proximity to the shore line
which fits very well in view of the lithological position in relation to the conglomerate horizon of normal facies. In the left hand corner at the top of zone 5, a miniature load ball is distinct and similar phenomenon can be observed at other points along the same line in this zone. Zone 6 is again a quartzose layer equivalent to zone 4. Zone 6 is succeeded by zone 7. The upper surface of zone 6 is undulating. This is possible due to a number of causes but in view of low degree of undulation it may be interpreted as a reflection of high viscosity at the time of deposition together with slight erosion. It may, however, be noted that the erosion of clay laminae is much more common and may be facilitated by its softness. Furthermore the strength of the current carrying the quartzose mass must be higher than the current depositing the clay laminae. Nevertheless a little erosion giving rise to an uneven upper surface in the quartzose band is observed and hence reported here. Zone 7 is divisible into two parts - 7a and 7b - separated by a more or less continuous light coloured band showing lensoid bedding. The lower surface is marked by miniature flame structures which are more pronounced in the succeeding sub-zone (7b). The sub-zone 7b is marked by pronounced flame structures together with three sand pockets in the right hand half of the zone. In the middle of the left hand portion, the lateral compression of the light coloured layer is very pronounced. The vertical compression has been explained by the assumption of shrinkage in the thickness during the process
of lithification of clay layers. But this lateral shrinkage is rather anomalous. This is explained by the idea that the tectonic folding is initiated in the pre-diagenetic stage itself and thus both vertical and lateral compressions can give rise to this type of structures which are very pronounced in the adjacent areas. The flame structures are very useful in determining the stratigraphic top and bottom. They also indicate the softness and the lack of internal cohesion of the clay laminae at the time of deposition of subsequent quartzose layers. In some cases, for example, at the top of this figure, the huge flame structure (marked F) may also indicate a similar circumstance under which air heave structures are produced. Though in the present case it may only indicate upward moving eddies which would pull some material of the clay fraction in an upward direction. The sand pockets are probably only due to the load of the overburden sinking in the cohesionless under layer. Zone 8 is a very thin zone of light coloured quartzose material showing lensoid shape in the right hand corner. Zone 8 is followed by zone 9 of very fine parallel laminations. The measurements show about 39 laminations in a thickness of 18 mm. The uppermost layer of this zone does not show erosion as seen in the zones 3, 5 and 7. This may be because zone 10 is a mixture of clay laminae in predominantly quartzose band as such this is more of a lithological gradation than a break. The upper portion of zone 10 shows very distinct cross-ripple laminations, the
top of which is distinctly eroded. Zone 11 has a symmetrical
distribution of clay laminae. Approximately in the centre
there are light coloured laminae, on the upper as well as
lower side of which the clay content progressively increases.
The base of the uppermost dark laminae with pronounced flame
structures in this zone is underlain by continuous light
coloured laminae (marked Y). The light coloured laminae show
thickening and thinning synchronous with the flame structure.
Zone 12 succeeds zone 11 and has the same general composition
as that of the other light coloured zones. On the right hand
side of the pronounced flame, convolutions become distinct.
They seem to have been developed on account of load casting.
An examination of the junction of zones 11 and 12 shows that
load casting and convolution are consistently present, though
not very distinct. Zone 11 appears to be micro-graded.

**Figure B:** This figure represents another polished surface
of the same specimen. On this surface very fine cleavage
traces are visible which correspond to the axial planes of
the penecontemporaneous deformation leading to convolute
laminations and flame structures. This observation supports
the recent suggestion by Williams et al. (1969) that the flow
cleavage can develop in unconsolidated sediments by rotation
of inequant grains in a fluid state in response to the movements
responsible for penecontemporaneous deformation. An interesting
feature in the cleavages is that they cut across different
lithological layers and as such are like axial plane cleavage, so much typical of the tectonic folding.

There is a fracture running across the specimen in this figure showing a small amount of displacement (with the left hand side as the down throw side). Apparently this is a normal fault of soft sediment stage. Such faulting is very common in this type of strata marked by penecontemporaneous deformation.

A few more turbidite sequences are described from the same horizon as those of figures A and B of plate 11. These cases are represented in plate 12 and plate 13.

**Figure A, Plate 12:** This figure represents a polished surface of a sample with the same gross lithology as described for the figures of plate 11. The succession starts from a dark coloured layer (marked 0), which is deposited over an ill-defined (broken while taking the sample) and irregular light coloured quartzose fraction. The surface of deposition is also irregular. This is followed by a very thin zone (1) of mixed composition showing cross-ripple laminations and very small scale load casting. This zone is followed by a zone (2) of very fine alternating light and dark coloured laminae. The light coloured laminae shows a tendency to develop lensoid shapes. The top portion of this zone (2) has miniature sand pockets. The succeeding zone (3) is comparatively thick and uniformly laminated by parallel dark coloured clay laminae of
razor sharp thickness. The next zone (4) is similar to zone 2 in composition consisting of laminated clay layers but shows distinct flame structures. Zone 5 is a light coloured laminated band similar to the zone 3 but shows pronounced pinch and swell structures. This may be due to load casting. The succeeding zone (6) is a very thin zone with very pronounced flame structures with the central flame (marked F) appearing like a light house, on the two sides of which there are very delicate auxiliary flames. On the right, in this zone, is developed a prominent sand pocket of the material of zone 7. Zone 7 is again very similar to zone 5. Zone 8 is a very distinct zone of clay laminations with indistinct flame structures. This zone is slightly disturbed by the peak of the flame F. The load cast (marked L) on the right hand side is rather pronounced and shows an anti-clockwise rotation. This zone is succeeded by zone 9 of very delicately laminated bands averaging about 6 laminations in a centimeter.

Figure B, Plate 12: This figure represents a polished surface of a specimen from the same stratigraphic horizon and with the same gross lithology as that of the samples described above.

Lowermost zone 1 in this sample is composed of laminated layers mostly parallel. The wavy appearance of some of the laminae is interesting and suggest a fluid state and uniform compression of some sort. This zone (1) appears to grade
into zone 2, the upper portion of which shows pronounced flame structures. The inclination of the symmetry planes of the flames to the left indicate some sort of directional flow from left to right which is not persistent in the next zone 3 which again shows flame structures. As we go up, the proportion of clay material decreases and the quartzose proportion increases. Even in zone 6 very feeble dark clay laminae with flame structure is persistent. The thickness of the light coloured bands within the dark coloured laminated bands becomes very pronounced in zone 6. This succession probably indicates a progressive increase of the current strength at this place. The overall grain size of the bigger grains also increases in this direction.

**Figure A, Plate 13:** The specimen represents layering of dark and light coloured band having an overall succession similar to that described in the previous paragraph. The interesting difference from the figures so far described from this horizon is that the shape distribution is markedly different in both the dark as well as the light coloured bands. The light coloured quartzose layers show much more intense load casting than in the samples described earlier. The dark layers show a far greater effect of turbulence resulting into flame structures of noticeable dimension. In a band of about 6 mm thickness the wave length ($\lambda$) and amplitude ($A$) (apparent) measure 9 mm and 6-7 mm respectively. It is interesting to note that the inequant grains of the
quartzose mass show parallel arrangement to the base of the trough formed by load casting. Similarly the clay laminae show a distinct tendency of bending in response to the load of the superincumbent strata. In some instances the quartzose bands show pinch and swell characters and the dark coloured layers show corresponding arching. The unequal thickness of the dark coloured layers may indicate that the clay size particles were more affected by the upward movement of the eddies and got concentrated in the central part coinciding with the thickest flame. This has an important significance regarding the fluid properties. Studies of highly fluid clays with water content upto 70% have indicated that these clays do not correspond in their viscosity and other properties to the Newtonian Fluids but require an initial momentum to overcome the resistance to flow which then on become free flowing (Smith, 1968). In the light of these observations it is of interest to find out whether the turbulent eddies had the mechanical strength and initial momentum to make the slurry move as more or less cohesionless free flowing fluid. The scattering of some bigger grains into the clay layers, even to the extent of creating pockets, is very significant in this regard. A look at the figure will convince that the particles show preferred orientation of pre-tectonic origin. This is rather surprising since the freedom of the particles has not resulted into any appreciable grading. It indicates that the particles had the freedom to rotate but probably
not enough freedom to sink and concentrate according to their size (surface area) or specific gravity. The load casting present is even on an extremely delicate scale. All this indicates a condition of high mobility, turbulence, and settling under agitated conditions not conducive to gradational bedding.

**Figure B, Plate 13:** This figure represents a polished surface of a calcareous quartzite-shale sequence having high porosity and showing considerable leaching. Lithologically it is similar to the samples described in the previous paragraphs. Light coloured bands and pockets are, composed of quartz grains and some dolomite of replacement character and feldspar is absent. The dark laminae are clayey and sometimes carbonaceous. The grain size is sub-microscopic in these laminae.

Zone 1 is a composite zone and is divided into sub-zones a, b and c. Sub-zone a (the lower light coloured laminae) is of a simple parallel lamination type. This is followed by sub-zone b, a light coloured band with lensoid pockets. The sub-zone c is a dark coloured clay layer of which the upper surface is highly eroded and preserves well-defined flame structures. This is followed by zone 2 of a lensoid sandy band showing intense load casting resulting into detached sand pockets. This is followed by zone 3 of rhythmic parallel laminations of dark and light colour. This is again succeeded
by a band (zone 4) of load casted lensoid sandy zone with incipient cross-ripple laminations. The top of this zone (4) is a eroded one, over which is deposited the clay layer (zone 5) similar to zone 1 and zone 3. At the top of zone 4 there are pockets of small size which are rather difficult to mark individually.

**Figure A, Plate 14:** This figure represents an X-ray radiograph of a dark coloured fine-grained quartzite which looks like a dark massive quartzite with no observable structures. In thin section the quartz grains are angular to sub-rounded, sorting is good and the average grain size is 0.01 mm. Considerable iron-ore is present. Tourmaline is also sometimes seen.

The specimen was prepared for X-ray radiographic treatment following the techniques already described for the figures of plate 24. The thickness in this case was kept at 2 mm only whereas for other samples it was 3 mm.

The succession in this figure starts with a disturbed zone of comparatively coarse-grained sand-sized quartz. This is followed by zone 2 of dark coloured fine-grained material without any visible planar structures. Zone 3 is a zone of very delicate parallel undulatory laminations. Zone 4 is similar to zone 2. Zone 5 is a zone of parallel laminations with a load casted base. From zone 5 downward there are two
very distinct fault planes. These reverse faults are of soft sediment stage. Starting from zones 1 and 2, one of these faults end in zone 6, which is a lense-shaped zone and the other end in zone 9. The faults are not persistent. Zone 7 is a lensoid light-coloured zone within the column of zone 6-8. Zone 6 and zone 8 may really be continuous within themselves. Zone 9 is divisible into two parts. The lower one is darker and the upper one is of light-coloured. The dividing line shows irregular flame structures. In rocks like these such structures are very useful in determining the top and bottom. Zone 10 is again a laminated zone followed by zone 11 of light-coloured sandy layer. Zone 12 is of undulatory laminations.

Figures B and C of plate 14 represents two typical cases of under surface markings recorded in these laminated quartzites.

**Figure B, Plate 14:** This figure represents under surface markings of a carbonaceous quartzite band within the massive Aravalli phyllites. The phyllites are also carbonaceous and preserve laminated structures only. The current direction in this figure is from left to right. The overlapping forms show a high degree of viscosity of the flow. In the central part of the figure there is a ropy structure.

This condition represents the denser flow preceding the
finer laminated bands represented by the laminites in the phyllites of this horizon. The grading is absent which shows that the slurry was too thick to permit the settling of particles giving rise to graded bedding. It represents an early stage of turbidity flow of shallow water zone.

Figure C, Plate 14: This figure again represents under surface markings in a carbonaceous quartzite band within the same phyllites as described above. The figure shows distinct flow direction (as marked by the arrow). This appears to represent a channel-fill structure. The current appears to have been strong or the viscosity lower than that of the previous case. Otherwise the environmental conditions appear to be the same as discussed above.

Group III - Argillaceous rocks:

This group is represented by the Aravalli phyllites. The field and the lithological account of these rocks have been discussed under appropriate heads. A few samples were polished and their sedimentary structures are discussed here.

Figures A and B, Plate 9: These two figures represent two polished surfaces of a laminated sample. These two surfaces are almost at right angles to each other. Lithologically the coarse-grained band in the middle of the sample is sandy and calcareous. The other laminae above and below this coarse-
grained sandy band are clayey layers which are light and dark coloured.

The lowermost zone in figure A represents simple parallel laminations which sometimes show micro-grading. Zone 1 is succeeded by zone 2 which contains structures of soft sediment deformation. Zone 2 is divided into two sub-zones, a and b, the latter one showing convolute laminations. The lithology of the laminae is the same as that of zone 1. The convolutions are of a chaotic nature. A slight erosional surface separates the two sub-zones. The convolutions have a horizontal axial plane in the left hand corner of the figure (A) and it becomes vertical on the right hand side. These laminations are micro-graded. This zone of convolute laminations is followed by a zone (3) of coarse sandy band showing intense load casting and giving rise to nests within the clay layers. The coarse sand fraction is replaced in part by some carbonate minerals. This zone is succeeded by a thick zone of parallel laminations (zone 4), the lower left hand part of which shows soft sediment faulting. In the middle part of this zone there is a light-coloured lamina (marked B) which shows a regular lensoid-shape parallel to the laminations. The thickness of the dark laminae increases upward in this zone. In a total thickness of 18 mm of this zone there are about 42 laminations of variable thickness. The next zone (5) appears to have been deposited over a slightly eroded surface of zone 4. This zone (5)
is a zone of cross-ripple laminations and is divided into two parts. The lower part is distinctly load casted. The lee side of the cross-ripple laminations is thickened but the stoss side is eroded due to the next flow of the current. This can be explained as the load casting is later than the deposition of cross-ripple lamination and the load casting has made the stoss side parallel to the flow of the next current which has deposited the upper part of the zone 5. This upper part of zone 5 is a thin layer of undulatory ripple laminations which are clear in the topmost portion. The ripple laminations appear to be more or less continuous with the thickened lee side. Zone 6 is a dark clay layer deposited over a slightly eroded surface of the zone 5.

In figure B of this sample the erosional surface of the zone 4 over which the zone 5 is deposited, is very distinct and the cross-ripple laminations show deformation through load casting. The stoss side erosion is distinct. The convolute laminations of zone 2 have enclosed some coarse replaced material. They are marked by N and N1. There are flame structures present in the lower horizon of the convolutions (zone 2). They have been marked F. It is interesting to note that the inclination of the flame structures is very much parallel to the axial plane of the convolute structures here.

**Figure A, Plate 10:** This sample is from the same horizon as the sample of figures A and B of plate 9. The gross
lithology is identical with the sample of figures A and B of plate 9.

The lowermost zone (1) represents simple parallel laminations of rhythmic nature consisting of light and dark-coloured laminae. The dark-coloured laminae show flame structures in the upper portion of this zone. This zone is succeeded by zone 2 showing convolute laminations with random folding of the soft sediment stage, tight in the left hand portion and rather open in the right hand portion. The axial planes of these folds (convolutions) point towards each other. This zone is succeeded by zone 3 which consists of coarse sandy material. The lower portion of this zone is not graded and seems to have been deposited over the eroded surface of zone 2. This zone (3) is graded in the upper portion and passes into fine laminations. Two faults of soft sediment stage are seen in the lower left hand portion. They merge into one another in the basal zone and in zones 2 and 3 appear as step faults. Zone 3 is succeeded by zone 4 of parallel rhythmic laminations showing very delicate soft sediment faulting. This zone seems to have been deposited over the eroded surface of zone 3. There are about 39 laminations of variable thickness and lithology in a breadth of about 18 mm. The top of this zone shows well-developed delicate flame structures. The presence of these structures is helpful in determining the top and bottom of the sequence
of the strata as the grading in such beds can be negative as well as positive. The next zone (5) is deposited over the eroded surface of the last dark-coloured layer of zone 4. Zone 5 is of cross-ripple laminations ('ripple drift' of Sorby, 1859 and Walker, 1963). The laminae are deformed by load casting and lateral compression. The cross-ripple laminations here too show thickening of the lee side and erosion of the stoss side. The uncommon stoss side erosion is due to the fact that the load casting has caused the stoss side parallel to the flow of the next current which has deposited the upper portion of the zone 5 after eroding the lower portion. The laminations in the upper portion of the zone (5) are more or less continuous with a little thickening of the lee side. This is a definite indication that the laminated beds are deposited by turbidity currents (Walker, 1963). The next zone (6) is of a composite nature consisting of sub-zones of the cross-ripple laminations with eroded tops, occasional load casting, and flame structures (marked F). Zone 7 is not fully exposed in this sample but represents rhythmic parallel laminations.

**Figures B and C, Plate 10:** These two figures again represent two oblique polished surfaces of a laminated sample from the same horizon and with the same gross lithology as that of the sample described above.

This sample represents light and dark-coloured rhythmic
alternations of simple parallel laminations. Zone 3 is of considerable importance showing diamond-shaped laminations. This could be also a kind of lensoid bedding with a more sharply curved bottom. This is marked L in figure B. In the photograph it is rather difficult to fix the stratigraphic top and bottom, though the shadow structures marked F may represent flame structures and may indicate the top. The specimen contains considerable amount of carbonaceous material.

Group IV - Carbonate rocks:

This group is represented by the interbedded limestones and the main band of limestone immediately to the east of Iswal which is mapped and described as Raialo limestone (Heron, 1953). The limestones are generally fine-grained and dark grey in colour. Quite a good deal of colour and grain size variation are seen in them and they appear, at least in some cases, interrelated.

Bedding in general is poorly defined in these rocks. Much of the lack of clarity appears to be related to the extensive solution activity seen in the rocks. Also lack of lithological contrast appears to affect the clarity of bedding. At a few places the bedding plane contacts were observed and wherever they were seen they were found to be somewhat irregular and ill-defined. Soft sediment deformation of
bedding is recorded at few places (Pl. 17, Fig. D). An interesting feature of this limestone is the presence of algal stromatolites and algal pisolites. The occurrence of these organo-sedimentary structures is patchy. The stromatolites have been successfully used as a criterion in establishing the succession in vertical and overturned strata (Pl. 17, Fig. A).

In the middle horizon of the limestone outcrop, irregular patches of pisolitic limestone are seen (Pl. 17, Figs. B and C). When silicified, the pisolites often stand out as blisters on the surface. They have been identified as oncoliths (V.V. Sastri, personal communication) which are considered to be of algal origin (Narozhnykh, 1964; Zhuravleva and Chumakov, 1968).

The presence of algal stromatolites in this limestone and its irregular and ill-defined bedding plane contact suggests the environmental conditions of deposition to be of shallow water. The depth must be shallow enough to allow the sun rays to penetrate the water so that the algae could grow (Pettijohn, 1957, p. 223; Ginsburg, 1955). The presence of algal pisolite suggests a turbulent water condition (Pettijohn, 1957, p. 409).

**Interpretation of Environments:**

Before we attempt an interpretation of the environment of
deposition on the basis of sedimentary structures described in the preceding pages, it will be necessary to note that these structures have been described from rocks of the Aravalli System, Raialo series and Delhi System as delineated by Heron in this area. The main belt of Delhi rocks is about 25 to 30 kilometers to the west of the present area and the so-called Delhis in this area are described as outliers of Delhi System by Heron. Recent studies of the officers of the Geological Survey of India (Poddar, 1965; Raja Rao, 1967; V.N. Sant and others as quoted by Mukthinath et al., 1969) and also the present study goes to show that the Delhi outliers could, in fact, be more convincingly interpreted as the littoral facies of the Aravalli System. The position of the Banded Gneissic Complex as the basement of the Aravalli System is also not undisputed. That the Banded Gneissic Complex is a metamorphic and migmatised equivalent of the Aravalli is convincingly recorded in some places (Crookshank, 1948; Sharma, 1953). However, near Udaipur and south of Udaipur (Parsad) there is very strong evidence to show that the Banded Gneissic Complex is the basement of the Aravalli System (Poddar, 1965). It will be presumed here that the Banded Gneissic Complex is the basement of the Aravalli rocks and the Delhi outliers are sensibly part of the Aravalli System, and a reconstruction of the environmental conditions of deposition will be attempted.

The lithology suggests a transgressive deposition starting
with the conglomerates and going upto the Aravalli phyllites of pelitic type. In between we have thin bands of Aravalli quartzites, arkoses and grits and thin successions of turbidities of proximal type, which have covered the regions of shallow water to medium depth (upto continental shelf).

Taking zone-wise, the distribution of rock types is as under:

1. Littoral zone : Conglomerates, grits, arkoses and quartzites with turbidities.

2. Neritic zone : Grits and quartzites + limestone and carbonaceous phyllites (normal facies). Turbidity flows represented by graywacke (phyllites) and laminites with abnormal structures.

3. Continental slope : Pelitic shales and fine-grained quartzites with thick bands of graywackes and laminites (not represented in this area).

4. Deep water zone : Not represented in this area.

Zone I:

The conglomerates, arkoses, grits and quartzites of this area have been mapped by Heron (1953) as Delhi outliers and rather strangely no conglomerates have been shown at the base of the Aravalli System. However, Heron mapped conglomerates at the base of the Aravalli System at Parsad
(24°11' : 73°42') about 48 kilometers south of Udaipur (Heron, 1953, p. 98). The geological evidence is very much in favour of considering these conglomerates as basal Aravalli rocks and they seem to represent the littoral zone sediments of the Aravalli geosyncline.

The pebbles are dominated by quartzite and the matrix is generally arkosic and rarely quartzitic. The provenance appears to be a quartzo-felspathic terrain. The general current direction is towards west and considerable fanning is present to the north-west and south-west. The regional strike of this group also represents the combined depositional strike, which is north-west south-east (to north-south in the south). It shows nearness to the shore-line which is substantiated by the typical lithology of the rocks.

There are thin bands of phyllite-quartzite interbedded sequences in the rudaceous belt. Their presence indicates the oscillatory nature of the basin. Furthermore most of these thin bands contain turbidites. They are the products of the instability of the basin.

The region as such represents proximal sediments deposited under extremely shallow water conditions and torrential currents. The relation between this and the turbidites of the phyllite-quartzite sequence is rather interesting. The turbidites of this region differ from those that occur to the south of the area (around Udaipur City, briefly discussed at the end
of this chapter) in being much more arenaceous than the others. The pelitic material is quantitatively small or absent and it is mostly the silty material which has been spread in thin turbidite layers (can be easily termed as 'muddy sand').

**Zone 2:**

The middle group is characterised by shallow water deposits of finer grain size than the grits and arkoses described so far. This zone has been the site of repeated agitations and has developed two distinct types.

(i) Normal facies, represented by fine-grained quartzite bands within the non-turbidite phyllites along with the dolomitic limestone with profuse development of algal pisolithes and algal stromatolites. The presence of these organo-sedimentary structures in the limestone and the association of this limestone with the orthoquartzite-grit of Iswal represents the orthoquartzite-carbonate consanguineous association. This association and the presence of these organo-sedimentary structures in the limestone is characteristic of shallow water turbulent environment (Pettijohn, 1957, p. 221-223 and p. 610-615; Ginsberg, 1955).

(ii) Turbidites represented by graywackes (phyllites) and laminites.

The normal sediments of this group appear to be immature and not well-differentiated. The main rock type, the phyllite,
shows considerable variation along the stratigraphic thickness. The variation is reflected in the variation of percentage of quartz, flaky minerals and the overall rapid change of grain size. The change of mineral composition, grain size, and the thickness of the individual beds is too rapid and indicates an unstable environment in this zone. The gross lithology in this zone is increasingly arenaceous. The fluctuating nature of the basin is reflected in the alternation of the sediments of coarse and fine grain-size (quartzite and phyllite). In this unstable zone, from time to time turbidity currents were generated through some sort of triggering effect, the mechanism of which is little understood. The turbidity currents had a westward direction and this is confirmed by the presence of deep water turbidites to the west of the present area. This zone contains only those turbidity deposits which resulted from the feeble disturbances originated in the littoral zone and settled down here (neritic zone). As a result it will be observed that the lutite contents in the rocks showing turbidity structures is low. Furthermore this low percentage of the lutite content has resulted into a striking absence of the well-developed graded bedding of various types, which is so very characteristic of the turbidites of the Udaipur area. These turbidite layers have functioned like thin blankets covering normal shallow water deposits which sometimes give a sort of unconformable relationship with the normal deposits. Strike variation between the turbidites and non-turbidites
becomes very striking where the area has undergone repeated deformation. Moreover difference in the competency of the strata makes the picture confused. This is true specially where quartzites and phyllites of normal facies, and turbidites are concerned in a folding episode. The turbidites represent a very insignificant time interval of instability resulting into thin bands within the shallow water deposits of a quieter period.

The overall picture in this zone as it emerges is as under:

The sediments of the normal facies deposited in the basin were mainly sands of different grades with a small pelitic fraction. Thin lensoid bodies of calcareous composition also formed at this stage. The freshly deposited sediments were agitated due to disturbances in the basin and the sediment in the upper layers got completely mixed up and resettled. By this process possibly the siliceous dolomites and the calcareous quartzites resulted. In the normal strata there are intervening thin bands of the turbidites represented by immature quartzite bands. The presence of laminites and the absence of well-developed graded bedding show that (i) either the water content was very high or (ii) the lack of clayey material deprived the turbulence of adequate viscosity which made the turbidity cloud cohesionless and permitted non-graded layering and good separation in extremely thin laminae without keeping the coarse grains in a suspended state.

In view of the continuity of the present area with the
Udaipur valley which shows typical turbidites, two typical structures are described here to emphasise the presence of the characteristic turbidites (Pl. 25) as well as typical laminites (Pl. 26) in the stratigraphic sequence.

Plate 25 represents a polished surface of a typical graded graywacke. This column can be divided into a number of zones. Zone 1 represents a very finely laminated pelitic zone. This is followed by a zone of graded graywacke. The positive grading is very distinct. The lower contact is sharp and shows distinct load casts. In the upper portion of this zone there are load-like structures which themselves may represent a variety of load casting. The middle portion represents a structural feature akin to the flame structures. This zone is followed by a light-coloured fine-grained muddy sand zone (zone 3) with a liberal distribution of coarse grains in it. This, in turn, is followed by a zone of parallel ripple laminations (zone 4). The interesting feature is that the graded bedding represents a type in which the fine grains are distributed throughout but coarse grains diminish upwards.

North of Udaipur valley (in the present area) the gross lithology shows some important gradational changes. The sand fraction gradually increases and ultimately becomes arenaceous. The quartzite bands described in association with the turbidites in the present area are in fact the equivalent representation of these graded turbidites of the Udaipur valley.
Plate 26 represents a polished surface of a typical laminite of Udaipur valley. The lowermost zone 1 represents dark-coloured clay fraction. Zone 2 represents a succession of parallel ripple laminations, cross-ripple laminations having their tops strongly eroded, and the basal zone showing distinct lensoid bedding. The erosional features of these laminations serve as a marker for the top and bottom in addition to the cross-ripple laminations as well as the flame structures. Zone 3 starts with parallel ripple laminations of lutite type and passes upwards into sandy fraction which is itself laminated in a very delicate manner. There are faults of the soft sediment stage in this zone. Zone 4 represents parallel laminations (unrippled). Zone 5 rests above the eroded top of zone 4, with a number of sub-zones of cross-ripple laminations with the middle portion showing parallel laminations. Each successive sub-zone shows distinct erosion of the top. Zone 6 is a zone of parallel laminations showing distinct flame structures at the top. Zone 7 is a zone of parallel laminations but due to erosion gives an impression of lensoid bedding. Zone 8 is again a dark-coloured pelitic layer and is succeeded by a zone very similar to the zone 5. The transverse cracks are parallel to the cleavage trends and function as fault planes. Some of these fault planes show distinct movement of the laminated portion. For example, in the zone 1 and zone 4 (in the top portion of the delicate laminated band) the faulting is very distinct. In addition to these, the
sedimentary injection (marked S), which have undergone distortion through compaction, are themselves parallel to the cleavage traces. So it seems that the formation of the cleavage started prior to diagenesis which could mean that tectonic deformation started before the diagenesis. This view finds support in the recent work of Maxwell (1962), Williams et al. (1969) and Johnson (personal communication).

The laminites of the Udaipur valley invariably cap the graded turbidites and probably represent the tail of the original turbidity current.

Representatives of the continental slope (zone 3) and deep water zone (zone 4) are not seen within the confines of the area under study.